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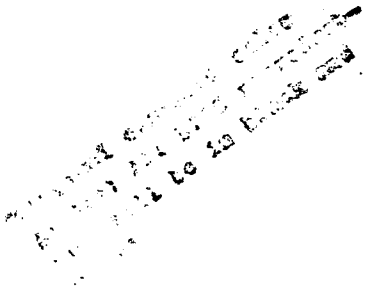
Degraded States Vulnerability Analysis of a Foreign Armored Fighting Vehicle

Mark D. Burdeshaw
John M. Abell
Scott K. Price
Lisa K. Roach

ARL-TR-299 November 1993



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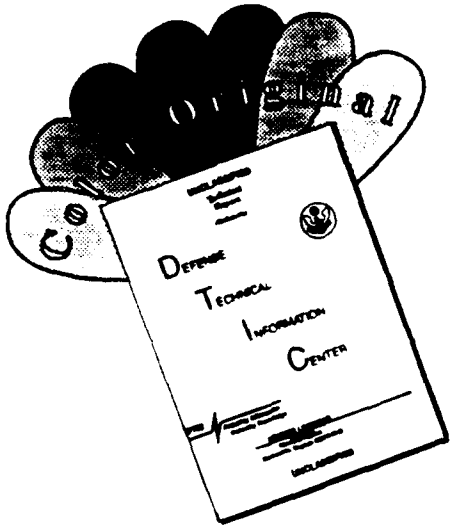

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Mark D. Burdeshaw, John M. Abell, Scott K. Price, and Lisa K. Roach

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13. ABSTRACT *(Maximum 200 words)*

Since 1990, the Ballistic Vulnerability/Lethality Division (BVLD) of the U.S. Army Research Laboratory (ARL) (formerly the Vulnerability/Lethality Division [VLD] of the U.S. Army Ballistic Research Laboratory [BRL], and the U.S. Army Materiel Systems Analysis Activity [AMSAA]) have been using the Degraded States (DS) Vulnerability Methodology (DSVM) for vulnerability calculations. The DSVM determines the (possibly) degraded, but operational, state of a combat system following an encounter with a damage mechanism. The methodology was tested on a U.S. armored fighting vehicle for both single shot (Abell, Roach, and Starks 1989) and view average vulnerability estimates (Abell, Burdeshaw, and Rickter 1990) for a representative set of initial conditions.

This report details the first analysis to be completed during implementation; specifically, a foreign armored fighting vehicle (AFV). As shown in previous degraded states analyses, the Degraded States metrics provide a more detailed vulnerability assessment than the Damage Assessment List (DAL) methodology. The purpose of this analysis was to illustrate further the value of the Degraded States metrics by comparing Degraded States results with DAL results and to expand the pool of combat systems for which Degraded States metrics have been calculated.

14. SUBJECT TERMS
degraded states vulnerability analysis; foreign armored tank, vulnerability analysis, vulnerability methodology, degraded states; vulnerability, lethality, tank, projectiles

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1. INTRODUCTION

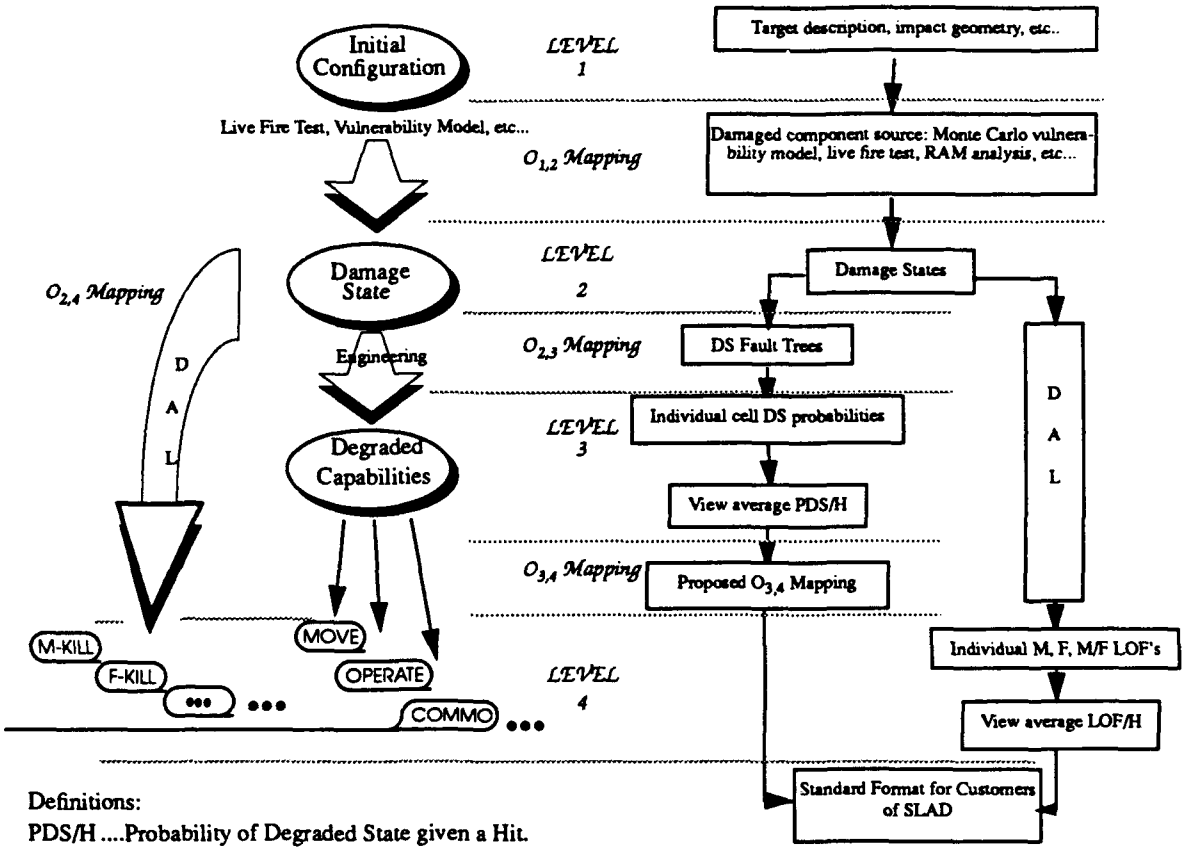
Since 1990, the Ballistic Vulnerability/Lethality Division (BVLD), of the U.S. Army Research Laboratory (ARL) (formerly the Vulnerability/Lethality Division of the U.S. Army Ballistic Research Laboratory [BRL]), and the U.S. Army Materiel Systems Analysis Activity (AMSAA) have been using the Degraded States Vulnerability Methodology (DSVM) for vulnerability calculations. The DSVM determines the (possibly) degraded, but operational, state of a combat system following an encounter with a damage mechanism. The methodology was tested on a U.S. armored fighting vehicle (AFV) for both single shots (Abell, Roach, and Starks 1989) and view average vulnerability estimates (Abell, Burdeshaw, and Rickter 1990) for a representative set of initial conditions.

During this implementation, the methodology will be applied to a number of combat systems, to include air and ground systems of both the U.S and foreign countries. Following the completion of the implementation stage in fiscal year 1994, the BVLD will begin full production use of the methodology. This report details the first analysis to be completed during implementation, specifically, a foreign AFV. As shown in previous degraded states (DS) analyses, the DS metrics provide more detailed vulnerability assessment than the Damage Assessment List (DAL) methodology. The purpose of this analysis was to illustrate further the value of the DS metrics by comparing DS results with DAL results and to expand the pool of combat systems for which DS metrics have been calculated. One objective of this analysis was to perform a comparison of the DS and DAL results. As a result of this analysis, it's been determined that this type of comparison is not worthwhile because of the fundamental difference in what the two metrics represent. As shown in the next section, DS provides an engineering based capability vector, while the DAL methodology provides a measure of combat utility. A comparison of these two fundamentally different vulnerability methodologies provides no useful information.

2. METHODOLOGY

2.1 Calculational Methodology. Figure 1 shows the overall process for calculating the DS and DAL metrics. The left side of the figure contains the vulnerability/lethality process structure and the right contains the diagram showing the calculational methodology. Sections 2.2 through 2.6 will describe each step of the process in more detail. The calculational methodology basically follows the vulnerability taxonomy outlined in the report by Klopcic et al. (Klopcic, Starks, and Walbert 1992). The top block shows the initial conditions and physical parameters, such as target geometry, that describe the interaction

between the target and threat (Level 1). The next block represents the $O_{1,2}$ mapping, which for this analysis was done by the Stochastic Quantitative Analysis of System Hierarchies (SQuASH) model. This mapping can be done by means other than a computer model, for example, live fire testing. The following block represents Level 2, which is the damaged component information. Up to this point, the necessary calculations were the same for both the DS and DAL methodologies. However, for the DSVM, the next step is to perform an $O_{2,3}$ mapping and for the DAL an $O_{2,4}$ mapping. Finally, the data is formatted for use by other agencies.



Definitions:
PDS/H ....Probability of Degraded State given a Hit.
LOF .....Loss of Function Value.
LOF/H ....Loss of Function Value given a Hit.
M .....Mobility.
F .....Firepower.
SLAD .....Survivability/Lethality Analysis Directorate.

Figure 1. Calculational methodology.

2.2 Initial Conditions. Table 1 contains the initial conditions which describe the target/threat configuration for this analysis. Four different munitions were used; two kinetic energy (KE) penetrators and two chemical energy (CE) penetrators. Large or marginal overmatch is defined with regard to the frontal armor. Large overmatch means that the munition has a substantial amount of residual penetration capability after perforating the armor. Marginal overmatch means that there is little or no residual penetration capability after perforating the frontal armor.

Table 1. Initial Conditions

Threats:	Large Overmatch KE. (KE2) Marginal Overmatch KE. (KE1) Large Overmatch CE. (SC2) Marginal Overmatch CE. (SC1)
Views:	0°, 30°, 60°, and 90°
Exposure:	Fully exposed and hull defilade.
Aim Point:	Center of presented area for each combination of view and exposure.
Dispersions:	1, 2, 3, 5, and 10 ft
Range:	500 m, 1, 2, and 3 km

View was defined as the azimuth and elevation from which the attacking munition strikes the target. The elevation used for all four azimuths was 0°. Zero degrees azimuth was the view from in front of the vehicle (looking down the barrel), 90° the view from the side (with the barrel pointing to the left), and 30° and 60° the two intermediate views.

The center of the foreign AFV presented area was used as the aim point, with a unique aim point for each combination of azimuth and exposure. In order to simulate weapon system delivery errors, the probability of hitting the vehicle in a particular location was calculated using the distance from the aim point and the dispersion. All combinations of bullet, dispersion, and range were examined. However, four ranges were used only for the KE penetrators because range was not a factor for CE penetrators.

2.3 SQuASH. The Vulnerability Methodology Branch (VMB) developed the stochastic point burst vulnerability model SQuASH (Deitz and Ozolins 1989) to generate lists of damaged components called

"damage vectors." (NOTE: The DSVM may be used with other sources of damaged component information such as live fire test results. It is not a requirement that DS be used with a stochastic vulnerability model). In addition, the portion of SQuASH which calculates the loss of function (LOF) values was modified to calculate the DS metrics. This computer program, called "SDS," was used to generate probability of DS given a hit (PDS/H) for the DS approach and, for comparative purposes, LOF values given a hit (LOF/H) using the DAL approach. There are several published reports which describe the SQuASH model (Deitz and Ozolins 1988), so there will be no further discussion of the model in this report. The inputs to the "SDS" model, including the damage vectors calculated by SQuASH, were provided by Mr. Lawrence Losie of the Ground Systems Branch (GSB) and Mr. Aivars Ozolins of the VMB.

2.4 Degraded States. The DSVM describes vehicle degraded capability in terms of measures of performance which are grouped into capability categories. For the foreign AFV, six capability categories were developed: mobility (M), firepower (F), acquisition, crew, communications, and K-Kill. This approach represents a more robust set of metrics than the traditional DAL metrics which provide LOF values only for M and F and the probability of K-Kill. Each DS capability category contains a set of capability levels which define degraded, but operational, states of the vehicle to include a "no damage" state. Since it is possible for two or more capability levels to occur simultaneously, all possible combinations of capability levels are considered in each capability category. Due to the inclusion of these combinations and the "no damage" state, the capability levels are both exhaustive and mutually exclusive within a particular capability category. For any given set of killed components, one capability level from each of the six capability categories will be satisfied. The combination of the six capability levels represents the degraded state of the vehicle. The complete list of capability levels for each capability category of the foreign AFV is contained in Table 2.

2.4.1 Definition of Capability Categories and Levels. For shorthand purposes, the alphanumeric name assigned to each of the capability levels will be used throughout the remainder of this report. For example, M3 represents the third capability level in the mobility capability category, which is total immobilization of the vehicle. The total number of possible combinations of the capability levels (DS) is as follows:

Table 2. Capability Categories and Levels

• Mobility M0 — No M damage M1 — Slight reduction in speed	 M2 — Significant reduction in speed M3 — Total immobilization
• Firepower F0 — No F damage F1 — Loss of main armament F2 — Unable to fire on the move F3 — Increased time to fire F4 — Reduced delivery accuracy F5 — Loss of secondary armament F6 — F2 and F3 F7 — F2 and F4 F8 — F3 and F4	 F9 — F2 and F3 and F4 F10 — F2 and F5 F11 — F3 and F5 F12 — F4 and F5 F13 — F2 and F3 and F4 and F5 F14 — F2 and F3 and F5 F15 — F2 and F4 and F5 F16 — F3 and F4 and F5 F17 — F1 and F5 (Total loss of firepower)
• Acquisition A0 — No acquisition damage A1 — Reduced acquisition capability	 A2 — Total loss of acquisition capability
• Crew C0 — No crew casualties C1 — Loss of driver C2 — Loss of commander C3 — Loss of gunner	 C4 — C1 and C2 C5 — C1 and C3 C6 — C2 and C3 C7 — Total loss of crew
• Communication X0 — No communication damage X1 — Loss of internal communication X2 — No external communication greater than 300 ft	 X3 — No external communication X4 — X1 and X2 X5 — X1 and X3 (Total loss of communication)
• K-Kill K0 — No K-Kill K-1— Ammunition K-Kill	 K2 — Fuel K-Kill K3 — K1 and K2

Combinations = number of M Capability Levels × number of F Capability Levels × number of Acquisition Capability Levels... etc.

Combinations = $4 \times 18 \times 3 \times 8 \times 6 \times 4 = 41{,}472$

2.4.2 Fault Trees. Fault trees are used to represent mathematically and graphically systems of components or specific performance capabilities. Components can be arranged in either series or parallel or some combination of the two. If listed in series, the loss of any one component would cause an

interruption in the path. For those components listed in parallel, at least one component in each branch must be killed to interrupt the path. For example, in Figure 2, if components 1 or 6 are killed (series), or if components 2 or 3, and components 4 or 5 are killed together (parallel), then this fault tree would be cut and the capability level it represents would be achieved. An ARL technical report provides a more detailed discussion of fault trees and their uses (Roach, 1993).

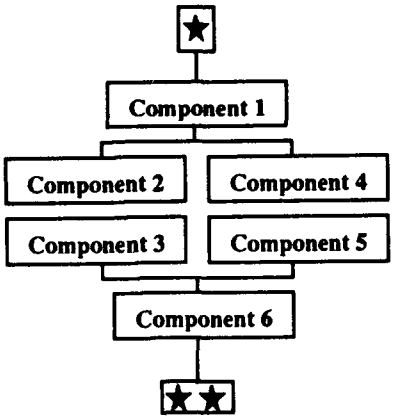


Figure 2. Example of a fault tree.

A criticality analysis for this vehicle was performed by Mr. Rick Grote and Mr. Michael Sivack of the Systems Assessment Branch (SAB) of the BVLD, and the results are contained in a separate report (Grote and Sivack 1989). This analysis defined the critical components and systems of the vehicle. The fault trees in the criticality analysis represent the interrelationships of critical components and systems with one another to define required functions such as traverse, elevate, and engine power. The DS fault trees, which use the criticality analysis, represent the degradation described by each capability level in each capability category. These fault trees consist of a list of critical vehicle components or systems that, if nonfunctional, would cause the particular capability level to occur.

After the initial DS fault trees were developed, they were reviewed by the appropriate personnel at ARL, AMSAA, the U.S. Army Combat Systems Test Activity (CSTA), and the U.S. Army Foreign Science and Technology Center (FSTC). Their recommended changes, if appropriate, were incorporated in the final fault tree configurations for each capability level. The fault trees were then translated into FORTRAN statements and incorporated into the "SDS" code. The complete set of vehicle fault trees is contained in Appendix A.

2.5 Damage Assessment List. The DAL used in this analysis (Grote, private communication). The list contains M, F, K, and M/F LOF values for each critical component and system in the vehicle. The complete DAL is shown in Table 3.

2.6 View Average Calculations. View average results for both the DS and DAL metrics were calculated for all combinations of initial conditions. In order to perform view average calculations, a grid system was overlaid on the target; in this case a 4-in grid cell system was used. There were 10 Monte Carlo iterations in each grid cell with a unique set of killed components for each iteration and 613, 1,084, 1,269, and 1,148 cells each for 0°, 30°, 60°, and 90° azimuth, respectively. "SDS" calculated the vulnerability estimates via the DS fault trees or the DAL for each iteration and then averaged the results over the entire view.

Table 3. Damage Assessment List for the Foreign Armored Fighting Vehicle

Event No.	M	F	K	M/F	Component(s)
1	0.60	0.55	0.00	0.60	Driver only
1	0.50	0.55	0.00	0.55	Commander only
1	0.50	0.60	0.00	0.60	Gunner only
1	0.95	0.95	0.00	0.95	Driver and Commander
1	0.95	0.95	0.00	0.95	Driver and Gunner
1	0.95	0.95	0.00	0.95	Commander and Gunner
1	1.00	1.00	0.00	1.00	All crew
2	0.00	1.00	0.00	1.00	Main gun only
2	0.00	0.10	0.00	0.10	Co-axial Machine gun (MG)
2	0.00	0.05	0.00	0.05	Anti-aircraft (AA) MG
2	0.00	0.10	0.00	0.10	Both MGs
2	0.00	1.00	0.00	1.00	Main gun and Co-axial MG
2	0.00	1.00	0.00	1.00	Main gun and AA MG
2	0.00	1.00	0.00	1.00	Main gun, AA, and Co-ax MGs
3	0.00	0.05	0.00	0.05	Bore evacuator
4	0.00	0.57	0.00	0.57	Primary fire control only

Table 3. Damage Assessment List for the Foreign Armored Fighting Vehicle (continued)

Event No.	M	F	K	M/F	Component(s)
4	0.00	0.38	0.00	0.38	Night fire control only
4	0.00	0.95	0.00	0.95	All fire control
5	0.00	0.00	0.00	0.00	Power elevate only
5	0.00	0.00	0.00	0.00	Manual elevate only
5	0.00	1.00	0.00	1.00	All elevate
6	0.00	0.00	0.00	0.00	Manual traverse only
6	0.00	0.05	0.00	0.05	Power traverse (stabilized) only
6	0.15	0.20	0.00	0.20	Commander's sight only
6	0.06	0.08	0.00	0.08	Commander's searchlight only
6	0.15	0.20	0.00	0.20	Power traverse (nonstab.) only
6	0.15	0.20	0.00	0.20	Power traverse (nonstab.) and commander's sight
6	0.15	0.20	0.00	0.20	Power traverse (nonstab.) and commander's searchlight
6	0.15	0.20	0.00	0.20	Power traverse (nonstab.), commmander's sight and searchlight
6	0.15	0.20	0.00	0.20	Commander's sight and searchlight
6	0.15	0.30	0.00	0.30	Power traverse stab. and nonstab.
6	0.15	0.30	0.00	0.30	Power traverse, stab. and nonstab., and commander's sight
6	0.15	0.30	0.00	0.30	Power traverse, stab. and nonstab., and commander's searchlight
6	0.15	0.30	0.00	0.30	Power traverse, stab., and nonstab., and commander's searchlight and sight
6	0.00	0.95	0.00	0.95	All traverse
6	0.00	0.95	0.00	0.95	All traverse and commander's sight
6	0.00	0.95	0.00	0.95	All traverse and commander's searchlight
6	0.00	0.95	0.00	0.95	All traverse, commander's sight and searchlight

Table 3. Damage Assessment List for the Foreign Armored Fighting Vehicle (continued)

Event No.	M	F	K	M/F	Component(s)
6	0.15	0.20	0.00	0.20	Power traverse (nonstab.) and manual traverse
6	0.00	0.05	0.00	0.05	Power traverse (stab.) and manual traverse
6	0.06	0.08	0.00	0.08	Commander's searchlight and manual traverse
6	0.15	0.20	0.00	0.20	Commander's searchlight, power traverse (nonstab.) and manual traverse
6	0.06	0.13	0.00	0.13	Commander's searchlight and power traverse (stab.)
6	0.06	0.13	0.00	0.13	Commander's searchlight and power traverse (stab.) and manual traverse
6	0.15	0.20	0.00	0.20	Commander's sight and manual traverse
6	0.15	0.20	0.00	0.20	Commander's sight, power traverse (nonstab.) and manual traverse
6	0.15	0.30	0.00	0.30	Commander's sight and power traverse (stab.)
6	0.00	0.95	0.00	0.95	Commander's sight and power traverse (stab.) and manual traverse
6	0.15	0.20	0.00	0.20	Commander's sight and searchlight and manual traverse
6	0.15	0.20	0.00	0.20	Commander's sight and searchlight, power traverse (nonstab.), and manual traverse
6	0.15	0.30	0.00	0.30	Commander's sight and searchlight and power traverse (stab.)
6	0.00	0.95	0.00	0.95	Commander's sight and searchlight, power traverse (stab.), and manual traverse
7	0.30	0.00	0.00	0.30	Driver's intercom
7	0.30	0.05	0.00	0.30	All intercoms
7	0.30	0.05	0.00	0.30	Driver's intercom and all intercoms
7	0.05	0.05	0.00	0.05	All radios
7	0.34	0.10	0.00	0.34	All communications
7	0.34	0.10	0.00	0.34	All communications and all radios
7	0.34	0.10	0.00	0.34	All communications and driver's intercom

Table 3. Damage Assessment List for the Foreign Armored Fighting Vehicle (continued)

Event No.	M	F	K	M/F	Component(s)
7	0.34	0.10	0.00	0.34	All communications and all intercoms
7	0.34	0.10	0.00	0.34	All radios and all intercoms
7	0.34	0.10	0.00	0.34	All communications, driver's intercom, and all intercoms
7	0.34	0.10	0.00	0.34	All communications, all radios, and driver's intercom
7	0.34	0.10	0.00	0.34	All communications, all radios, and all intercoms
7	0.34	0.10	0.00	0.34	All communications, all radios, all intercoms, and driver's intercom
7	0.34	0.05	0.00	0.34	Driver's intercom and all radios
7	0.34	0.10	0.00	0.34	Driver's intercom, all radios, and all intercoms
8	1.00	0.00	0.00	1.00	All throttle, service brake, left and right steering, and shifting
9	0.05	0.00	0.00	0.05	Driver's periscope
10	1.00	0.00	0.00	1.00	Engine, engine lube system, trans/powertrain, fuel supply, fuel injector lines
11	1.00	0.00	0.00	1.00	Left and right idler wheels
12	0.50	0.00	0.00	0.50	Left #1 roadwheel only
12	0.50	0.00	0.00	0.50	Right #1 roadwheel only
12	0.75	0.00	0.00	0.75	Left #1 and right #1 roadwheels
13	0.20	0.00	0.00	0.20	Left #6 roadwheel only
13	0.20	0.00	0.00	0.20	Right #6 roadwheel only
13	0.36	0.00	0.00	0.36	Left #6 and right #6 roadwheels
14	0.05	0.00	0.00	0.05	One intermediate roadwheel, either left or right
15	0.10	0.00	0.00	0.10	Two intermediate roadwheels, either left or right
16	0.15	0.00	0.00	0.15	Three intermediate road wheels, either left or right

Table 3. Damage Assessment List for the Foreign Armored Fighting Vehicle (continued)

Event No.	M	F	K	M/F	Component(s)
17	0.20	0.00	0.00	0.20	Four intermediate roadwheels, either left or right
18	1.00	0.00	0.00	1.00	Left or right drive sprocket
19	1.00	0.00	0.00	1.00	Left or right track
20	0.00	0.00	0.00	0.00	Manual loading
20	0.20	0.75	0.00	0.75	Power autoload
20	0.25	0.80	0.00	0.80	Power and manual loading
21	0.05	0.00	0.00	0.05	One support roller, either left or right
22	0.10	0.00	0.00	0.10	Two support rollers, either left or right
23	0.35	0.00	0.00	0.35	Three support rollers, either left or right

3. OUTPUT

The results of this analysis were voluminous due to the number of initial condition combinations and the nature of the DS output. This section will discuss the various forms of output obtained from both the model and the post processing of the data. Vehicle results will be discussed in Section 4.

3.1 Degraded States and Damage Assessment List Output. With DS, a single vehicle DS was produced for each iteration; therefore, each cell could have contained up to 10 different vehicle DS. After calculating the 10 iterations in the cell, an unweighted probability of occurrence for each DS that occurred was calculated (number of occurrences divided by 10). Next, the weapon system delivery error was accounted for by multiplying the DS probabilities by the probability of hitting that particular cell. This produced the weighted DS probabilities for each cell. For example, Table 4 shows the different vehicle DS obtained within a single cell (see Section 2.2.1 for DS capability levels). First, the DS for each of the 10 iterations is listed. After the individual iteration results, the DS that occurred in that cell are listed along with their unweighted probabilities of occurrence. Lastly, the DS are again listed, this time with the weighted probability of occurrence (probability of occurrence multiplied by the probability of hitting that location). After the DS were calculated for each cell, they were averaged over, the entire view, which resulted in the probability distribution of DS as will be discussed in the next section (Section 3.2).

Table 4. Example of a Single Cell Degraded States Output

Iteration	MFACXK	
1	000200	
2	000200	
3	000200	
4	000200	
5	000200	
6	200202	
7	000202	
8	000200	
9	300202	
10	300200	
States	Unweighted Probability	Cumulative
000200	0.6000	0.6000
300200	0.1000	0.7000
300202	0.1000	0.8000
000202	0.1000	0.9000
200202	0.1000	1.0000
States	Weighted Probability	Cumulative
000200	0.0000097	0.0000097
300200	0.0000016	0.0000113
300202	0.0000016	0.0000129
000202	0.0000016	0.0000145
200202	0.0000016	0.0000161

For the DAL, the result of each iteration was a set of four LOF values, M, F, K, and M/F, thus generating 10 sets of LOF values for each grid cell. The unweighted LOF values for each cell were then calculated by taking the average of these 10 values. The weighted LOFs were produced by multiplying the unweighted LOFs by the probability of hitting the cell.

As one can see, the DS output provides information normally lost during the DAL aggregation process. In addition to detailed information on the M and F, further information is available on crew, communication, and acquisition. For example, using the DS distribution, the frequency of inflicting one, two, or three crew casualties can be determined. Also, the probability of a particular capability level in

one capability category occurring simultaneously with a particular capability level in another capability category can be calculated. For example, it may be desirable to know how frequently the entire crew is killed (C7) when no catastrophic kill has occurred (K0).

3.2 Probability Distribution of Degraded States. The probability distribution of vehicle DS was the primary output from this analysis. A unique distribution was generated for each set of initial conditions (all possible combinations of threat, range, azimuth, exposure, and dispersion). The distribution consists of a set of vehicle DS listed in descending order according to their probabilities of occurrence and the associated cumulative probabilities. This output provides, in detail, the frequency and degree of the damage in each of the six capability categories. Table 5 is an example of a probability distribution of DS. The full set of probability distributions for this analysis are on file at BVLD for further reference.

Table 5. Example of a Probability Distribution of Degraded States for a Full View

Target ID:	FOREIGN TANK	—
Threat:	Large KE	—
Azimuth:	0 °	—
Dispersion:	2 Ft	—
STATE	PROBABILITY	CUMULATIVE
000000	0.32041	0.3204092
300000	0.04744	0.3678451
000401	0.04256	0.4104015
000002	0.02685	0.4372555
000001	0.02614	0.4633998
. .	. .	. .
100201	0.00016	0.9994809
111251	0.00016	0.9996380
311252	0.00013	0.9997655
391002	0.00013	0.9998931
091351	0.00011	1.0000000

These probability distributions were provided to AMSAA for input to their force level model, DS Weapons Analysis Research Simulation (DSWARS) (Comstock 1989). For force level comparisons, a set of traditional DAL metrics (M, F, K, and M/F) for each set of initial conditions was also provided to AMSAA. The comparisons permit a limited assessment of the effect of DS metrics in a force level model.

One concern facing the force level modelers was the large number of possible vehicle DS. However, for any combination of initial conditions, the number of vehicle DS realized was considerably less (no more than 250) than the 41,472 possible combinations. Eighty percent of the cumulative probability was accounted for within the first 10 DS for defilade runs and the first 35 DS for fully exposed runs.

In Section 3.5, methods of aggregating DS metrics to permit numerical comparisons with the DAL metrics are discussed. However, the probability distribution of DS is the most powerful form of the data, and it is this form that, in general, should be used. For example, in a high fidelity combat simulation which has the capability of playing vehicle top speed, firing rate, target acquisition capability, etc., it would be more realistic to use DS data which provides this information as opposed to the DAL data which is generally used incorrectly as a probability of no capability.

3.3 Tabulation of Degraded States Capability Level Probabilities. Damage to the vehicle was accounted for in many different vehicle DS and probabilities by the DSVM whereas the DAL provides a single LOF value. Each individual capability level and its associated probability were extracted from the probability distribution of DS to examine their variability across the initial conditions. A utility code was developed to extract the individual DS capability level probabilities from the full view probability distribution for each set of initial conditions (threat, exposure, azimuth, range, and dispersion). The full set of tabulated DS probabilities is on file at BVLD for future reference with an example of the tabulated DS output shown in Table 6. The first two rows show the initial conditions. Then the capability categories are listed in row 3, one capability category per column. The capability levels are listed in the first column with columns 2 through 7 containing the weighted probabilities of the individual capability levels.

3.4 Tabulation of Damage Assessment List Loss of Function Values. Like the DS capability level probabilities, the DAL LOFs were also put into a tabulated format according to the initial conditions. Appendix D contains the DAL LOFs for each set of initial conditions with an example of the tabulated DAL output shown in Table 7.

Table 6. Tabulated Degraded States Capability Level Probabilities

THREAT ID:	Large KE	RANGE:	1 km	EXPOSURE:	Fully	
AZIMUTH:	0°	DISPERSION:	2 ft			
Capability Level	Mobility	Firepower	Acquisition	Crew	Commo	K-kill
0	0.7480	0.6509	0.7535	0.3497	0.8880	0.4823
1	0.1924	0.2203	0.2465	0.0414	0.0001	0.4682
2	0.0102	0.0000	0.0000	0.0402	0.0001	0.0281
3	0.0495	0.0018	—	0.0917	0.0031	0.0214
4	—	0.0000	—	0.3271	0.0000	—
5	—	0.0000	—	0.0046	0.1087	—
6	—	0.0000	—	0.0665	—	—
7	—	0.0000	—	0.0787	—	—
8	—	0.0000	—	—	—	—
9	—	0.1270	—	—	—	—
10	—	0.0000	—	—	—	—
11	—	0.0000	—	—	—	—
12	—	0.0000	—	—	—	—
13	—	0.0000	—	—	—	—
14	—	0.0000	—	—	—	—
15	—	0.0000	—	—	—	—
16	—	0.0000	—	—	—	—
17	—	0.0000	—	—	—	—

3.5 Aggregated Degraded States Metrics. Because of the fundamental difference between the DS (mathematical probability) and the DAL (LOF value) metrics, a direct comparison was impossible. However, because the DAL methodology has been the de facto standard for vulnerability assessments for many years, and DAL LOF values have been used as probabilities of no capability, it was necessary to aggregate the DS metrics in a way that would facilitate a comparison of the magnitude and trends of the

Table 7. Tabulated Damage Assessment List Loss of Function Values

THREAT ID: AZIMUTH: EXPOSURE:	Large KE 0° Fully	RANGE: DISPERSION:	1 km 2 ft	
View Average (weighted):	M: 0.550	F: 0.556	K: 0.354	MF: 0.615

two metrics. The full view distribution of DS probabilities were aggregated by three different methods for this purpose.

3.5.1 Aggregation for Damage Assessment List Comparison. Since the DAL considers components such as radios and crew members when calculating M and F LOFs, the DS metrics were first aggregated to include these items. This aggregation facilitated comparison of the DS metrics to the DAL LOFs and is listed below:

Aggregated M = P (any M capability level or any crew capability level or any communication capability level or K-Kill)

Aggregated F = P (any F capability level or any acquisition capability level or any crew capability level or any communication capability level or K-Kill)

Aggregated M or F Kill = P (any M capability level or any F capability level or any acquisition capability level or any crew capability level or any communication capability level or K-Kill)

Note that one problem with aggregating DS probabilities in this manner is that all capability levels within a category count equally when calculating an aggregated value even though they may represent different levels of damage. For example, the probability of M1, reduced speed slight, would be counted the same as the probability of M3, total immobilization.

3.5.2 Total Kill Aggregation. Although the DAL metrics are LOF values, they have been used in the past as probabilities of no capability. With the total kill aggregation, values for M, F, and M or F were created from the DS probability distributions. These values represent the probabilities of total loss of M capability, total loss of F capability and total loss of either M or F capability, and were obtained as follows:

Total M Kill = P (M3 or three crew kills or K-Kill)

Total F Kill = P (F1 or A2 or any two or three crew kills or K-Kill)

Total M or F Kill = P (M3 or F1 or A2 or any two or three crew kills or K-Kill)

The primary drawback to this method of aggregation is that partial damage is completely ignored and in some cases partial damage is substantial. With this method of aggregation, one loses the partial damage information which is explicitly represented in the full distribution.

3.5.3 Mission Kill Aggregation. A third method of aggregation was employed to create values which would represent mission kill (MK) metrics. MK metrics are intended to account for and interpret the physical damage to a combat system, both lethal and nonlethal, in mission relevant terms. For a complete discussion of MK concepts, see the report by the Committee for the Technical Review of MK Initiatives, DARPA/Army/USMC Joint Program Office for Armor/Antiarmor Technologies (Otis et al. 1990) and the draft report by Mr. David Hardison (1992). The MK metrics represent three functions: Move (M), Communicate (C), and Operate (O), as well as an overall MK value. The MK aggregation was accomplished as follows:

Move = P (any M capability level or K-Kill)

Operate = P (any F capability level or any acquisition capability level or K-Kill)

Communication = P (any commo capability level or K-Kill)

Mission Kill = P (any capability level or any F capability level or any acquisition capability level or any commo capability level or K-Kill)

The MK metrics, as defined in the Committee's report, are LOF values. Since MK metrics treat the crew separately, it was decided that crew would be considered separately from M, C, and O for purposes of this aggregation. Therefore, the MK aggregation is the same as the "DAL-like" aggregation without the crew included, and it suffers from the same drawbacks as the DAL aggregation (see Section 3.5.1).

3.5.4 Cell Plots. The highest resolution of the "SDS" output, the cell by cell data, was used to generate individual cell plots for both the DS probabilities and the DAL LOFs. This output contained the unweighted probability of DS (PDS) or DAL LOFs for each 4-in cell in the view. The plots are color coded on a scale of 0 (white) to 1 (red) with the color of the cell corresponding to the probability of the DS or the DAL LOF value.

Cell plots will be displayed throughout Section 4.0 to highlight key points and will illustrate the amount of detail available with DS metrics. Note, there are only four possible plots that can be made with DAL metrics, M, F, K, and M/F. With DS, cell plots of individual capability level probabilities or the probabilities of some type of appropriate aggregation can be made. It is important to note that the DS cell plots of individual capability levels contain the probabilities of only those capability levels. Recall that the DAL includes LOF values for communication, target acquisition, and crew components in the M and F values.

4. RESULTS

In Section 4.1, the sensitivity of the DS probabilities and DAL LOF values vs. the various input parameters are examined to ensure that the results are reasonable. General trends of the probabilities and LOFs are identified and presented with illustrative examples. In Section 4.2, numerical comparisons are made between the DS and DAL results, and finally, in Section 4.3, cell plots are used to illustrate DS vs. DAL results. However, not all results or outputs are included. Due to the volume and nature of the output, some data are contained in the appendices and other data, not considered necessary to present the results, will be maintained at the ARL and are available upon request to the authors and establishment of need to know. Appendix B contains the complete set of probability distributions of DS for all combinations of initial conditions. Any other outputs or results not presented in Section 4 to illustrate the results are maintained at the ARL.

4.1 Sensitivity Comparisons. Unless otherwise stated, the DAL-like aggregated M or F DS metric was used for the comparisons to the DAL (see Equation 3).

4.1.1 Range. The ability of the CE penetrators to penetrate armor is independent of range. Therefore, range was not an input parameter for the CE rounds. Of the two KE threats, the marginal overmatch penetrator, KE1, was more affected by range than was the large overmatch penetrator, KE2. The variation of the aggregated M or F probabilities and the DAL LOF values were greatest at 0° azimuth and least at 90°. Neither threat showed much variation across range at 90° azimuth because both of the KE penetrators had large overmatch capability against the thinner side armor (see Figures B-1 to B-4).

4.1.2 Range and Dispersion. Next, the range and dispersion were varied together using the range/dispersion pairs shown in Table 8. The trend of the DS probabilities and the DAL LOF's was decreasing across range and dispersion for 0° with both exposures, and 90° with fully exposed. However, at 90° with hull defilade, the trend was increasing across range and dispersion for both DAL and DS.

Table 8. Range and Dispersion Combinations

Range	Dispersion
500 m	1 ft
1 km	2 ft
2 km	5 ft
3 km	10 ft

This increasing trend was caused by a number of factors and the interrelationships between the different aimpoints for defilade and fully exposed, the dispersions, the location of F components within the turret, and the differences in the effectiveness of the two types of penetrators to kill the main gun tube. Also, recall that the probabilities and LOF values are given a hit. These values were calculated by dividing the PDS or LOF value given a shot by the probability of hitting the target. As the dispersion increased, the probability of hitting the vehicle decreased dramatically, causing the PDS/H to increase across dispersion (see Figures B-5 to B-8).

4.1.3 Dispersion. The same trends were seen for dispersion as for the range/dispersion combination except for the CE rounds at 90° with hull defilade (see Figures B-9 to B-12). In this case, the trend increased from 1 ft to 5 ft dispersion and then decreased from 5 ft to 10 ft (see Figures B-13 and B-14). This was in contrast to the KE penetrators which increased across dispersion from 1 ft to 10 ft (see Figures B-15 and B-16). This was caused by the difference in the ability of the two types of penetrator to kill the main gun tube. At the higher dispersions, the contribution of the gun tube became increasingly important and since the CE penetrators do not kill the tube as readily as the KE penetrators, the PDS and LOF values given a hit do not increase when the dispersion goes from 5 ft to 10 ft.

4.1.4 Threat. A general result at 0° azimuth with fully exposed was that the two KE penetrators caused more damage than the CE penetrators. In fact, the marginal overmatch KE penetrator was more effective than the large overmatch CE penetrator. These results were reasonable for these threats based on prior analyses (see Figures B-17 and B-18). The penetrators, in order of greatest damage to least damage are:

(1) Large KE Penetrator (KE2),
(2) Small KE Penetrator (KE1),
(3) Large CE Penetrator (SC2),
(4) Small CE Penetrator (SC1).

At 90° azimuth with fully exposed, all four penetrators were capable of perforating the lightly armored sides of the vehicle, causing nearly the same amount of damage. The probability of aggregated M or F ranged from 0.70 to 0.80 while the DAL M/F LOF value ranged from 0.66 to 0.74.

At 0° and 90° azimuth with hull defilade, the large CE caused more damage than the small CE and the same for the KE penetrators. Also, the KE penetrators caused more damage than the CE penetrators.

4.1.5 Azimuth. Like most AFVs, this vehicle has the heaviest armor in the front, where it is most likely to be engaged. Also, as shown below, the smallest presented area was at 0° azimuth. The presented area, in square feet, for each azimuth of a fully exposed vehicle is shown in Table 9. Therefore, when fully exposed, the AFV was least likely to be hit from the front (0°) and was least vulnerable when hit at this azimuth. Likewise, the vehicle was most vulnerable when hit from the side (90°). When the vehicle was in defilade, the trends across azimuth for the marginal overmatch bullets were increasing. For

KE2, the trends for DS and DAL increase from 0° to 60° and decrease slightly from 60° to 90°. This slight decrease can be attributed to the shift of the aimpoint when the azimuth changed from 60° to 90°. Recall that there was a unique aimpoint for each combination of azimuth and exposure and the aimpoint was the center of presented area of the target. At 90° azimuth, the aimpoint was farther forward on the turret than at 60° because the gun tube had greater presented area. For SC2, the trend across azimuth is not clear cut (see Figures B-19 to B-22).

Table 9. Presented Area for Fully Exposed Vehicle

Azimuth	Presented Area (Ft^2)
0	68
30	120
60	141
90	128

4.1.6 Exposure. The vehicle was, of course, much more vulnerable when fully exposed for all threats and all conditions (see Figures B-23 and B-24). However, it is interesting to note that even when the vehicle was in hull defilade, it was still significantly vulnerable to K-Kill for KE2, which was due to the large amount of overmatch for this threat. (See Tables 10 and 11.)

Table 10. Probability of K-Kill (in percent) for Fully Exposed, 1-km Range, 2-ft Dispersion

Threat	0°	30°	60°	90°
SCI	5.4	12.7	29.5	39.6
SC2	15.6	22.4	36.8	47.5
KE1	20.2	27.9	39.0	44.9
KE2	35.4	38.9	44.2	47.4

4.2 Numerical Differences Between Degraded States and Damage Assessment List Metrics. In Section 4.1, the trends across the various input parameters for both DS and DAL were discussed. In all

Table 11. Probability of K-Kill (in percent) for Defilade, 1-km Range, 2-ft Dispersion

Threat	0°	30°	60°	90°
SCI	0.2	0.1	0.2	0.3
SC2	7.1	2.5	3.6	5.0
KE1	4.8	2.9	4.2	5.4
KE2	9.8	6.9	8.7	7.5

cases, the trends were very similar for the two metrics. In this section, the magnitudes of the two metrics for selected conditions are compared.

Since the DS metrics are more detailed than the DAL metrics, the DS results had to be aggregated to create single values for M, F, and M/F. Although there are many ways this aggregation can be done, three methods were chosen, as discussed in Section 3.5. In this section, the magnitudes of each M or F aggregation are compared to the DAL M/F metric.

Comparisons were made for all four munitions, 0° and 90° azimuth, fully exposed and hull defilade, 1-km and 2-ft dispersion. The first method, "DAL-like" aggregation, was consistently greater than the DAL. The ranges of the differences and the average differences are shown in Table 12.

Table 12. Magnitude Differences Between Damage Assessment List-Like Aggregation and Damage Assessment List

		Mobility/Firepower		Mobility		Firepower	
	Azimuth	Range of Diff.	Avg. Diff.	Range of Diff.	Avg. Diff.	Range of Diff.	Avg. Diff.
Fully	0	0.05 to 0.07	0.06	0.05 to 10.0	0.07	0.04 to 0.08	0.06
—	90	0.04 to 0.06	0.04	0.03 to 0.07	0.05	0.03 to 0.04	0.04
Defilade	0	0.05 to 0.10	0.07	0.01 to 0.05	0.03	0.05 to 0.10	0.07
—	90	0.03 to 0.07	0.05	0.02 to 0.04	0.03	0.03 to 0.08	0.06

Table 13. Degraded States vs. Damage Assessment List Mobility Example

Iteration Number	Degraded State	Damage Assessment List Mobility of Loss of Function Value
1	000000	0.0
2	100000	0.2
3	100000	0.2
4	100000	0.2
5	200000	0.5
6	200000	0.5
7	200000	0.5
8	300000	1.0
9	300000	1.0
10	300000	1.0
Average Cell Mobility Loss Of Function: 0.51		

Table 14. Degraded States Probabilities

Degraded State	Probability
000000	0.1
100000	0.3
200000	0.3
300000	0.3

To help explain why the "DAL-like" aggregation was greater, a M example from one particular cell is illustrated below. In the following table the DS and DAL results are listed for each of the 10 iterations performed in that cell.

Using the M LOF values from the table above, the cell average M LOF value is 0.51. In the next table is shown the probabilities for each of the four different DS that occurred.

From Equation 1, an aggregated DS M value is calculated:

$$M = P(\text{any M}) + P(\text{any C}) + P(\text{any commo}) + P(\text{any K-Kill}) = 0.9.$$

With this method of aggregation, there is no distinction between slight and significant damage. To obtain the DAL-like aggregated DS metrics, the probabilities of all damage levels, from slight to severe damage, were summed together with all damage treated equally. For the DAL metrics, the view average LOF values were calculated by averaging the expected LOF values from each cell in the view.

The second method of aggregation was called TK. This method represented the probability of total loss of M capability, total loss of F capability and total loss of M or F capability. The TK metrics were consistently less than the DAL metrics because they did not consider less than severe damage. This comparison shows that when DAL metrics are used as probabilities of no capability, the vulnerability of the vehicle can be overestimated. See Table 15 for the ranges of the differences and the average differences.

Table 15. Magnitude Differences Between Damage Assessment List and Total Kill Aggregation

		Mobility/Firepower		Mobility		Firepower	
	Azimuth	Range of Diff.	Avg. Diff.	Range of Diff.	Avg. Diff.	Range of Diff.	Avg. Diff.
Fully	0	0.04 to 0.08	0.06	0.05 to 0.11	0.09	0.04 to 0.07	0.06
—	90	0.03 to 0.05	0.04	0.09 to 0.11	0.10	0.03 to 0.05	0.04
Defilade	0	0.07 to 0.14	0.11	0.02 to 0.09	0.05	0.07 to 0.14	0.10
—	90	0.08 to 0.16	0.11	0.06 to 0.09	0.08	0.01 to 0.15	0.08

The third method of aggregation created K metrics. The differences between the K metric and the DAL metrics were very small. There are two important points to highlight about the K metrics. First, all levels of damage are considered from slight to significant. This tended to drive the K metrics higher than the DAL. Secondly, crew and K-Kill were not used in the aggregation. This fact tended to drive the DAL metrics higher than the K metrics. The end result of these two opposing tendencies was that the

final numbers close. Table 16 shows the ranges of the differences and the average differences between the DAL metrics and the K aggregation.

Table 16. Magnitude Differences Between Damage Assessment List and Mission Kill Aggregation

		Mobility/Firepower		Mobility		Firepower	
	Azimuth	Range of Diff.	Avg. Diff.	Range of Diff.	Avg. Diff.	Range of Diff.	Avg. Diff.
Fully	0	−0.03 to 0.03	0.01	0.02 to 0.08	0.05	−0.01 to 0.08	0.04
—	90	−0.01 to 0.04	0.02	0.08 to 0.10	0.09	−0.01 to 0.02	0.00
Defilade	0	0.02 to 0.08	0.05	0.02 to 0.09	0.05	−0.02 to −0.07	−0.05
—	90	0.01 to 0.06	0.03	0.06 to 0.10	0.09	−0.13 to 0.00	−0.05

The K aggregation produced the closest approximation to the DAL even though crew and K-Kill were not considered in the aggregation. The "DAL-like" aggregation, while considering all of the same components as the DAL, was consistently greater than the DAL and by a larger amount than the other methods of aggregation. Once again, this was caused by summing together the probabilities of all damage, from slight to total, with equal weight. The TK aggregation, while intended to represent the probability of no capability as the DAL has been used, was consistently less than the DAL because less than severe damage was not considered. These are the only three ways in which the DS probabilities may be aggregated if it is not possible to use the full spectrum of DS results or if a comparison to the DAL is desired. However, as has been shown, each method of aggregating DS metrics has its limitations. The power of the DS metrics is the detail and resolution of the full probability distribution.

4.3 Cell Plots. Cell plots (probability plots) are used to display the probabilities of each individual cell in the view. The color scale is shown in Figure 2. White corresponds to 0 and red corresponds to 1 with grey, blue, green, and yellow representing the intermediate probabilities. In this section, cell plots are used to illustrate key points with regard to modeling differences between the DAL and DS methodologies. The important differences that will be highlighted are:

- DS provides greater resolution, more detail than the DAL methodology. The DAL metrics lack the robustness to support the many types of item level and force level modeling.

- When used with a stochastic point burst vulnerability model like SQuASH, DS provides mathematically correct probabilities instead of LOF values. DAL metrics are commonly, and improperly, used as probabilities of no capability.

- The process of developing DS fault trees is correctable and auditable. DAL conclave participants must mentally integrate over all combat missions and scenarios making it difficult to change the DAL.

Figure 3 shows the cell plots for the three DSVM capability levels and the DAL M LOF values for all four threats at 90° azimuth. The first column on the left contains the cell plots for slight reduction in speed, column two shows significant reduction in speed, column 3 has the cell plots for total immobilization, and the column on the far right has the cell plots for the DAL M LOF values. One immediately notices that DS provides greater detail than the DAL. With DS, it is clear what parts of the vehicle are causing either slight or significant reduction in speed or total loss of M capability, and because DS provides probabilities, it is known how frequently these levels of damage occur. The DAL, on the other hand, only provides an average LOF value over 10 trials, from which it is impossible to determine the level of damage or the frequency of the damage.

In addition, for the DAL a great deal of M kills take place in the turret while for DS this does not happen. This is caused by including crew, communication, and K-Kill in the DAL M LOF value. DS, on the other hand, has separate capability categories for these functions. Therefore the damage to these components does not contribute to M degradation, and thus, there are no M kills in the turret with DS.

Figure 4 shows the cell plots for the DS F capability levels and the DAL F LOF values for all four threats at 90° azimuth. The first column shows the probability plots for loss of main armament. One obvious result is that the two CE penetrators kill the main gun tube about 20% to 30% of the time while the KE penetrators kill the gun 100% of the time. This is a result of the way in which the gun tube PK/H was modeled in the SQuASH program. Also, all four threats were able to produce main gun kills by killing components in the turret (as shown by the colored cells in the turret areas of the silhouettes). These main gun kills were primarily caused by loss of turret electric power, which causes loss of fire control capability, and loss of hydraulic power which in turn causes loss of power traverse and power elevate. Although manual backups exist for power traverse and elevate, if they are lost simultaneously

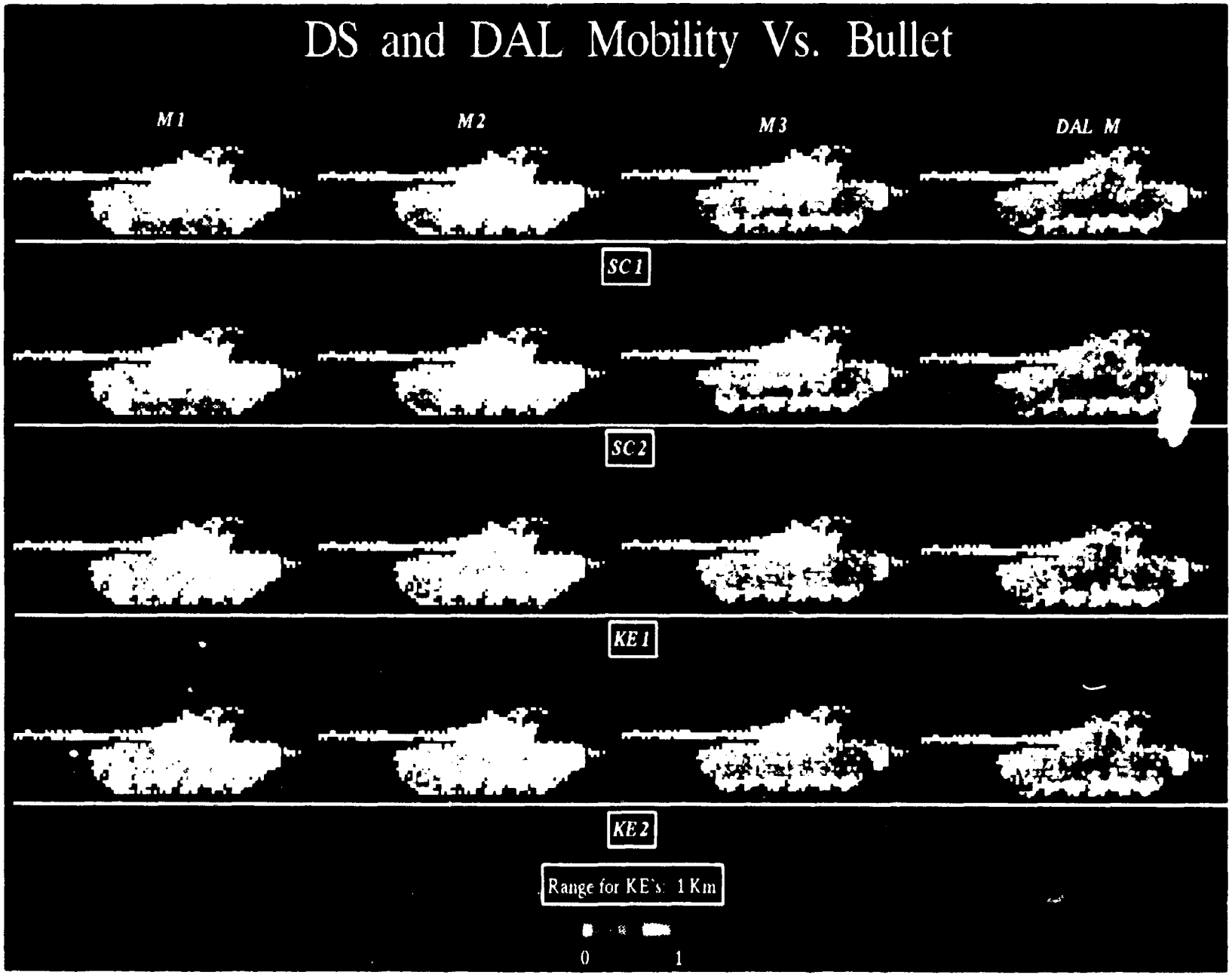


Figure 3. Degraded states and Damage Assessment List mobility vs. bullet.

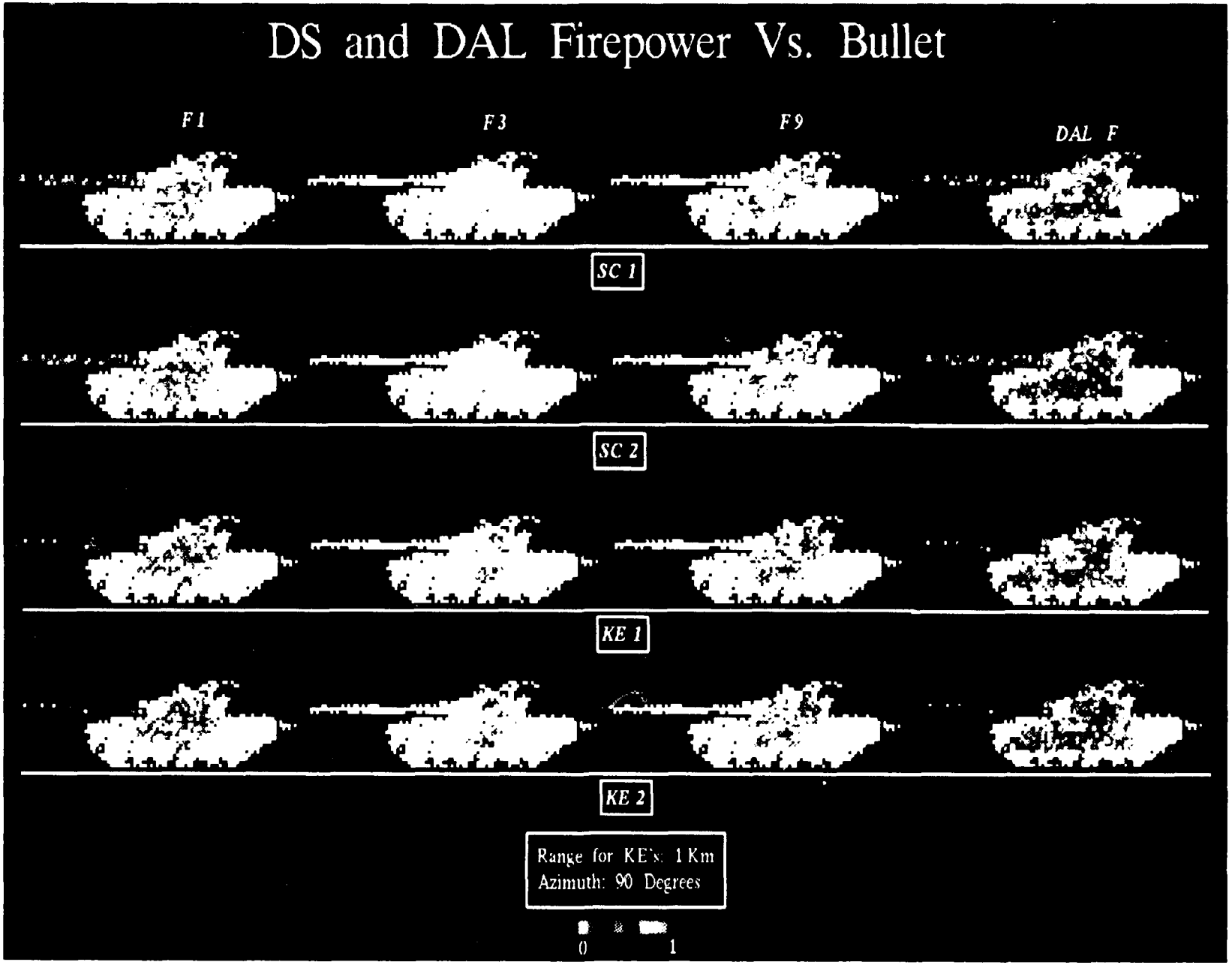


Figure 4. Degraded states and Damage Assessment List firepower vs. bullet

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it becomes virtually impossible to deliver accurate fire in any reasonable fashion. The second column shows the probability plots for increased time to fire (F3) and the third column shows the combination of unable to fire on the move, reduced delivery accuracy, and increased time to fire (F9). Increased time to fire (F3) was primarily caused by losing stabilized power traverse, power elevate, primary fire control, or power autoload. Capability level F9 was due to losing stabilized and nonstabilized power traverse or elevate, primary fire control, or power autoload. As with the previous cell plot for M, DSVM provides much more detail than the DAL methodology, which is shown in the fourth column.

5. CONCLUSIONS

The purpose of this analysis was to illustrate further the value of the DSVM and to expand the pool of combat vehicles for which DS metrics have been calculated. The vulnerability of a foreign AFV to a variety of threats and under various initial conditions was examined. The SQuASH model was used to generate the damaged component information which in turn was used to calculate the DS and DAL metrics. Numerous comparisons were made between the DS and DAL results, including sensitivity comparisons, numerical differences, and cell plots. The primary conclusion from the DS versus DAL comparisons is that this type of comparison is fundamentally meaningless. As shown in Figure 1, DSVM is an O2,3 mapping procedure which produces a Level 3 metric, or a capability vector. The DAL methodology is an O2,4 mapping procedure which produces a Level 4 metric, namely a measure of combat utility. A comparison of these two different vulnerability methodologies provides no useful information.

DSVM provides several important advantages over the traditional DAL methodologies. First, DSVM provides greater resolution and more detail than the DAL methodology. The DAL metrics lack the robustness to support the many types of item level and force level modeling done in the analytical community. Cell plots of the DS and DAL metrics show the greater resolution and detail that the DSVM provides. Secondly, when used with a stochastic, point burst vulnerability model like SQuASH, DSVM provides

mathematically correct probabilities instead of LOF values. Because DS metrics are probabilities, the level of damage and the frequency of that damage can be determined; the DAL metrics provide expected LOF values from which it is impossible to determine the level of damage or the frequency. Thirdly, the process of developing DS fault trees is correctable and auditable. Fault trees may be reviewed at any time during the analytical process to determine the accuracy of the results and to correct the fault trees if needed. Corrections to the DAL may require a reconvening of the conclave. As this analysis shows, the DSVM provides a robust accounting of remaining combat system functionally following an encounter with a damage mechanism.

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APPENDIX A:
DEGRADED STATES FAULT TREES

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This appendix contains the fault trees for each of the DS capability levels as defined for the foreign AFV. The title of the fault tree appears at the top of the diagram, and the boxes in the fault tree contain the names of the systems and components they represent. A forthcoming ARL report will provide a more detailed discussion of fault trees and their uses (Roach, to be published).

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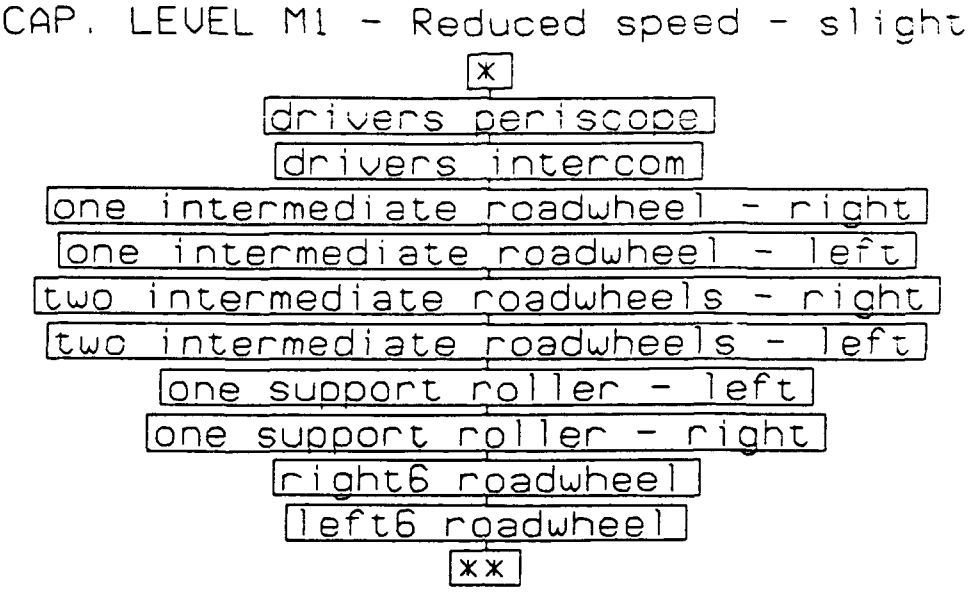

Figure A-1. Fault tree for reduced speed, slight.

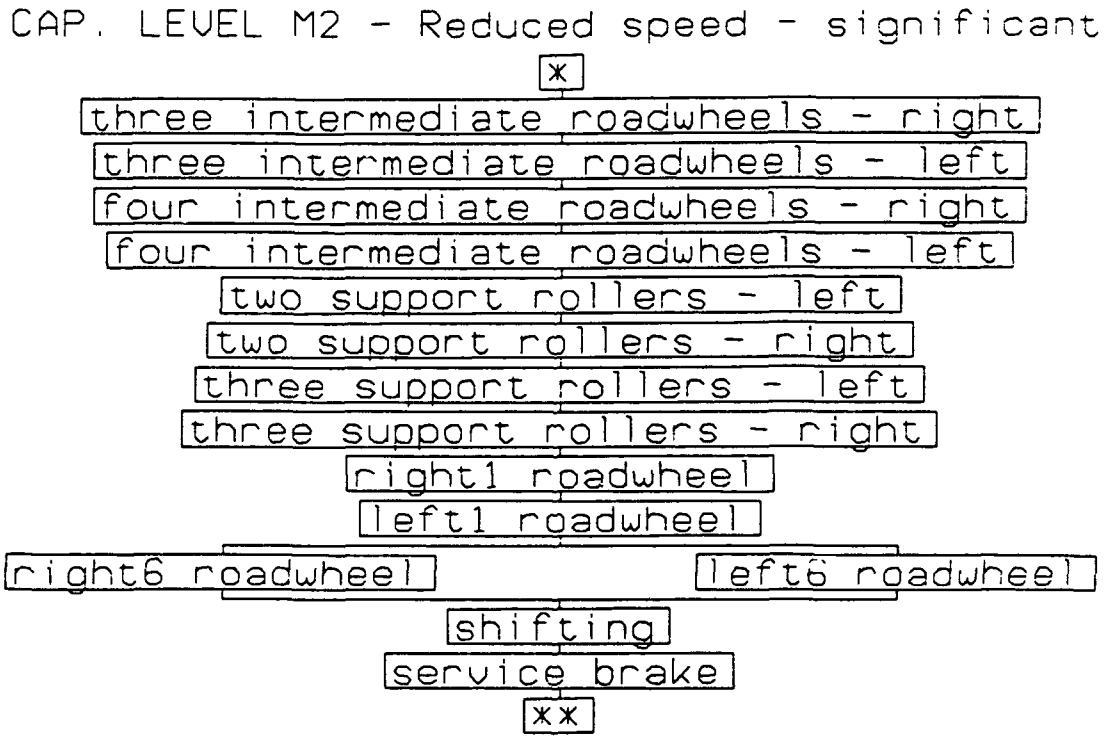

Figure A-2. Fault tree for reduced speed, significant.

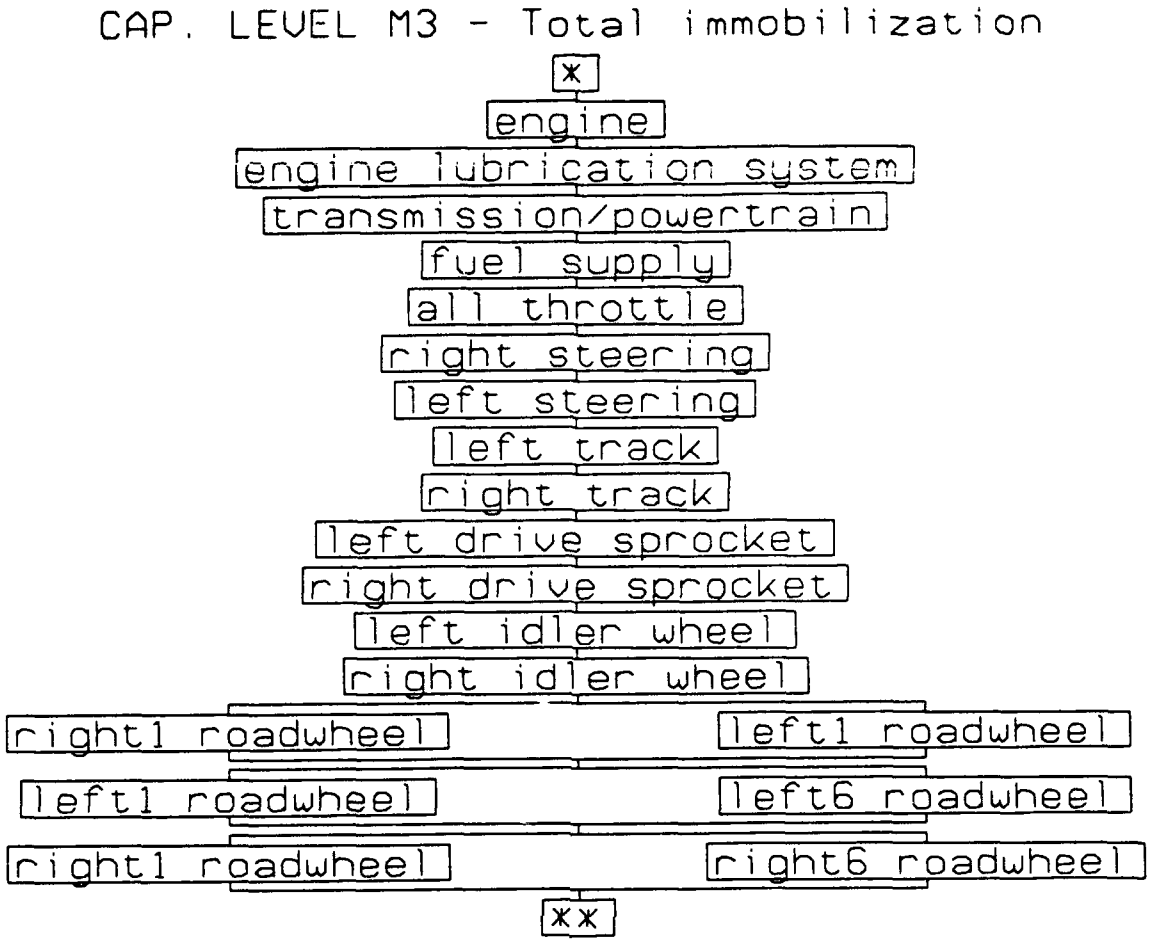

Figure A-3. Fault tree for total immobilization.

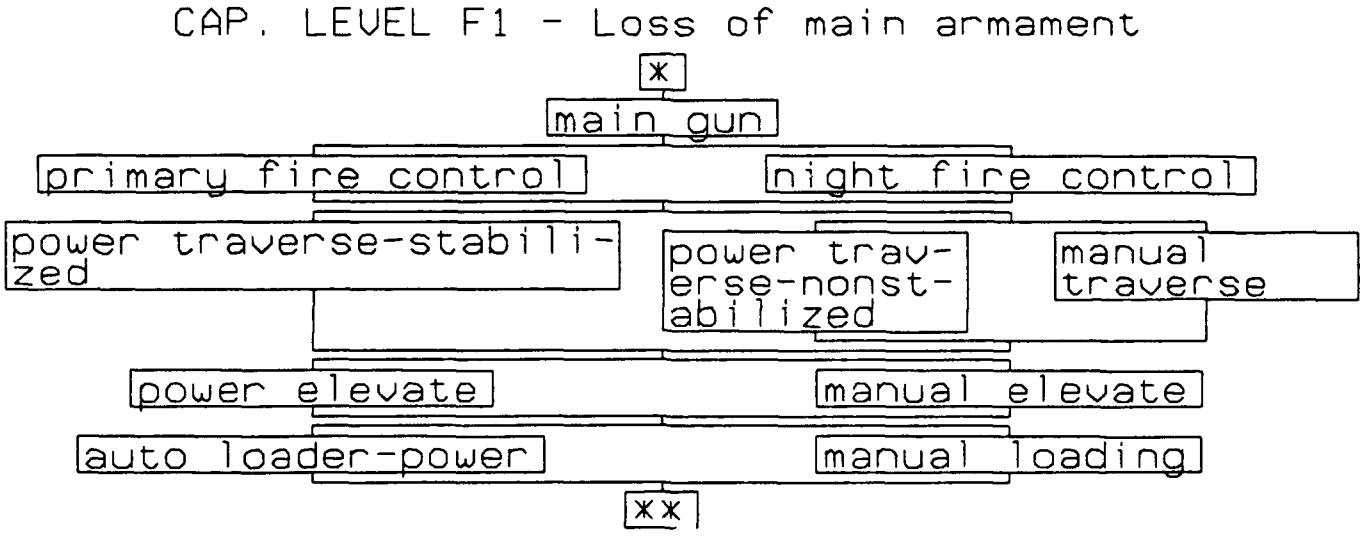

Figure A-4. Fault tree for loss of main armament.

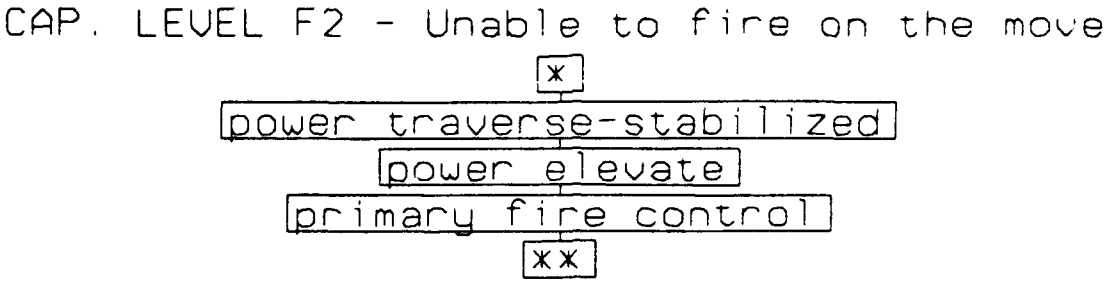

Figure A-5. Fault tree for unable to fire on the move.

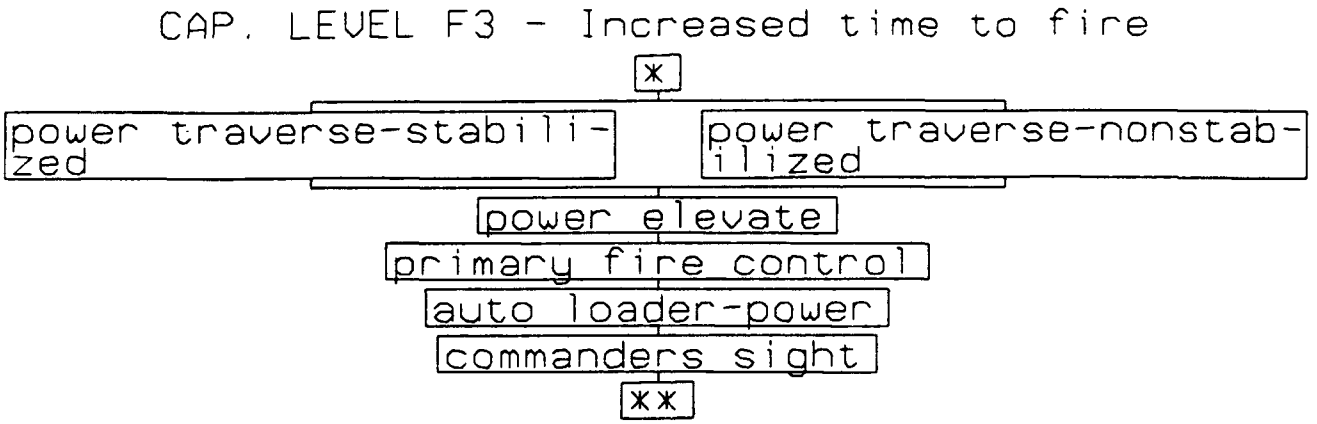

Figure A-6. Fault tree for increased time to fire.

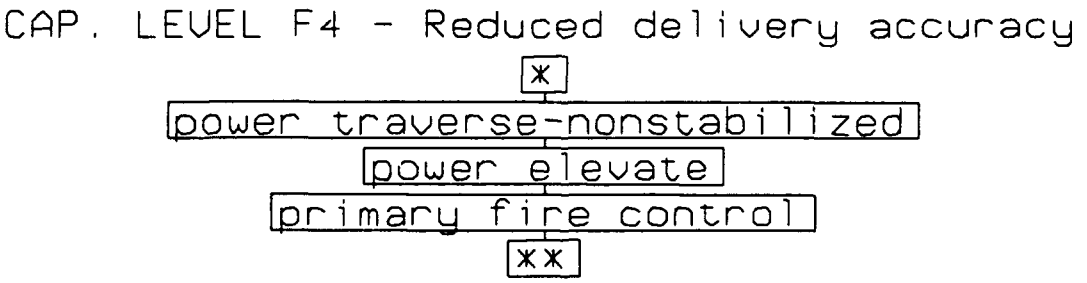

Figure A-7. Fault tree for reduced delivery accuracy.

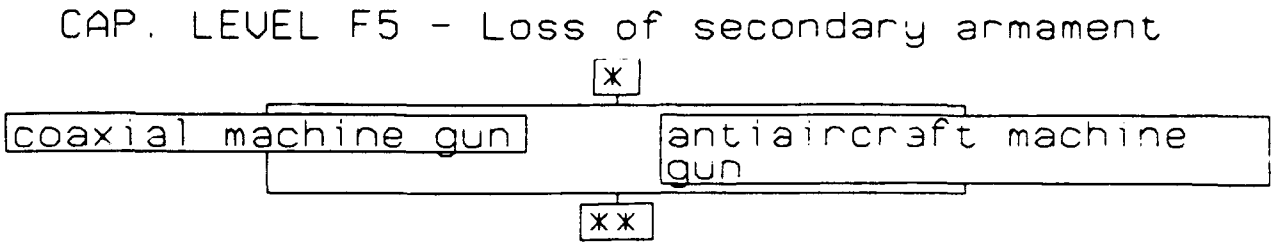

Figure A-8. Fault tree for loss of secondary armament.

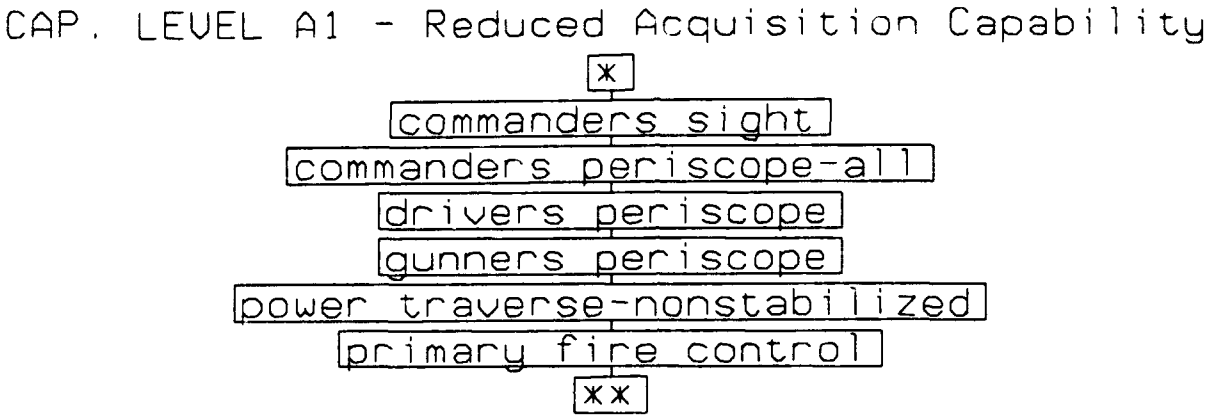

Figure A-9. Fault tree for reduced acquisition capability.

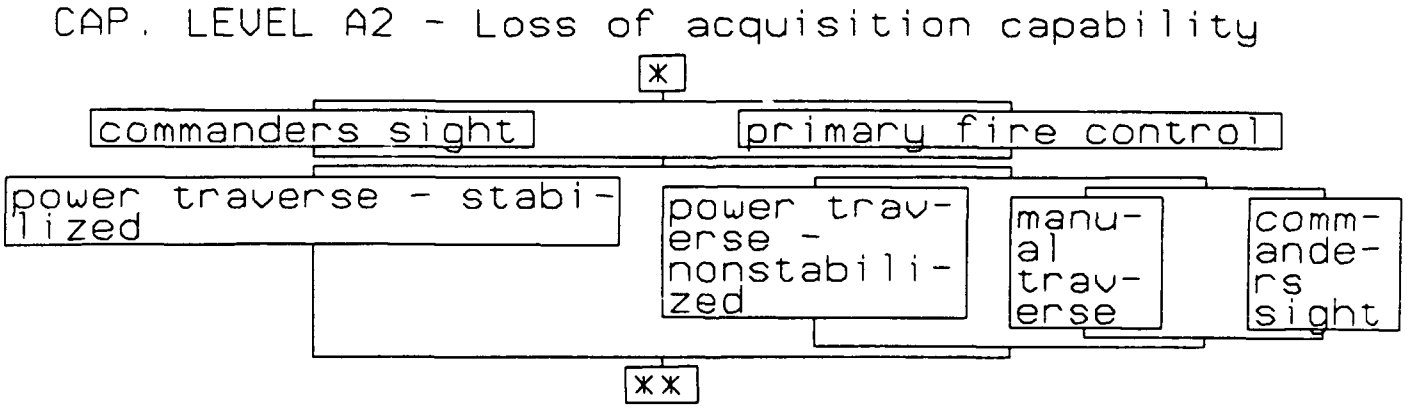

Figure A-10. Fault tree for loss of acquisition capability.

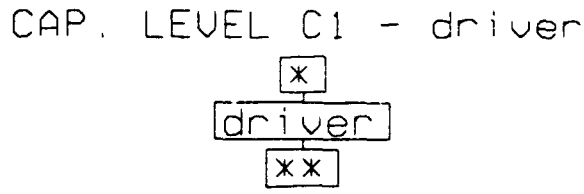

Figure A-11. Fault tree for loss of driver.

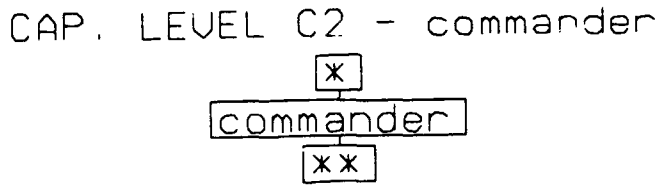

Figure A-12. Fault tree for loss of commander.

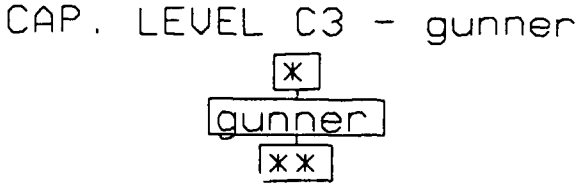

Figure A-13. Fault tree for loss of gunner.

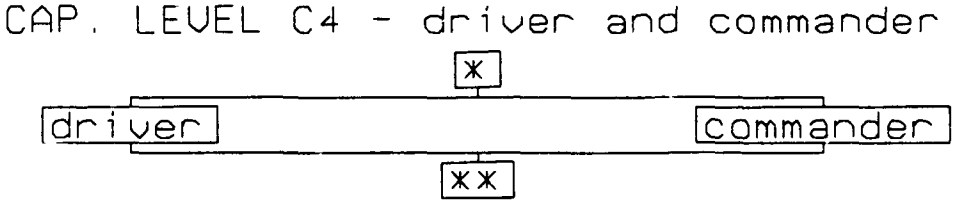

Figure A-14. Fault tree for loss of driver and commander.

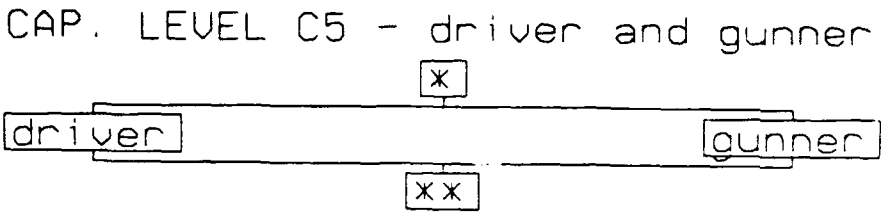

Figure A-15. Fault tree for loss of driver and gunner.

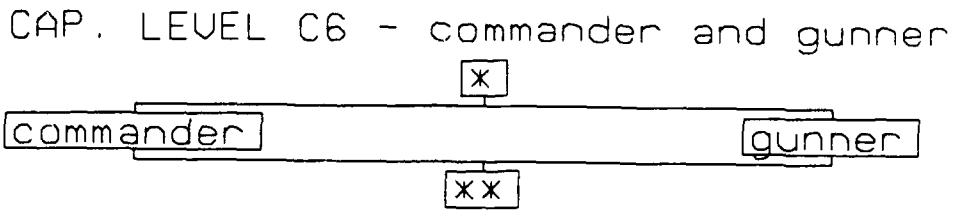

Figure A-16. Fault tree for loss of commander and gunner.

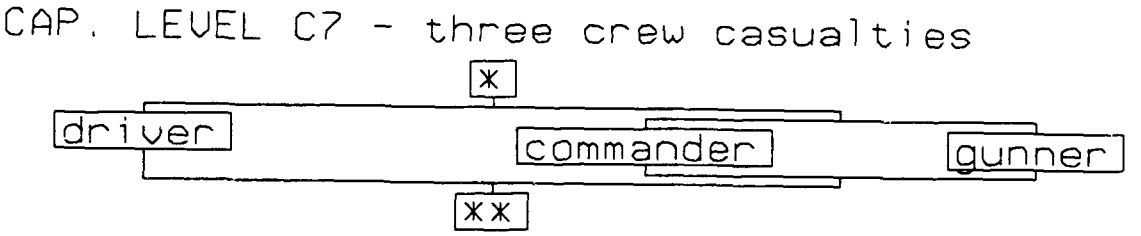

Figure A-17. Fault tree for total loss of crew.

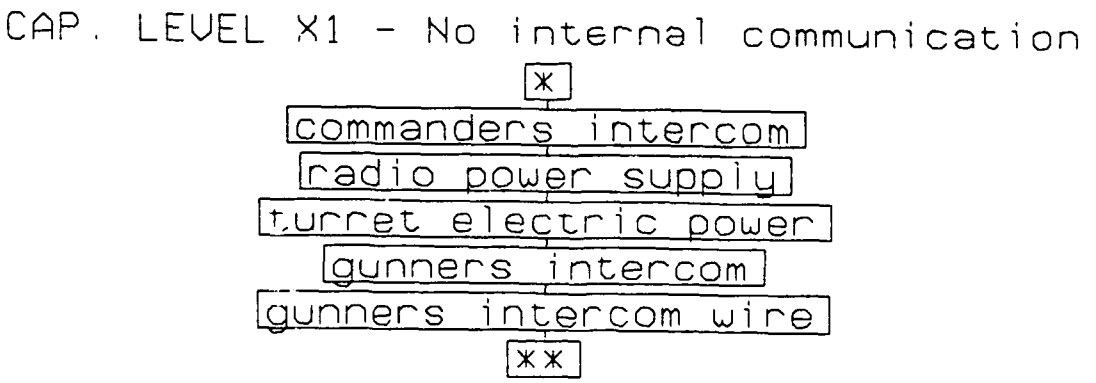

Figure A-18. Fault tree for no internal communication.

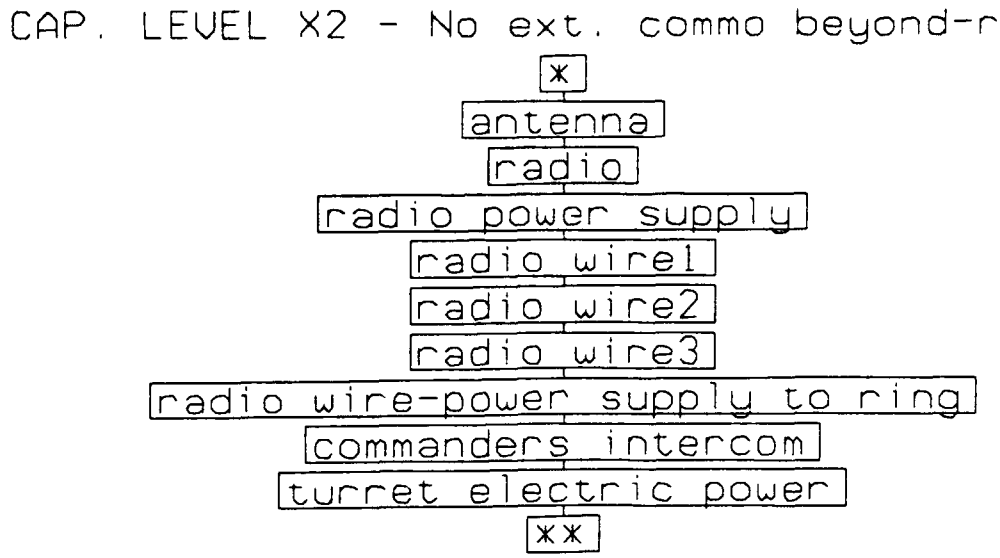

Figure A-19. Fault tree for no external commo beyond 300 ft.

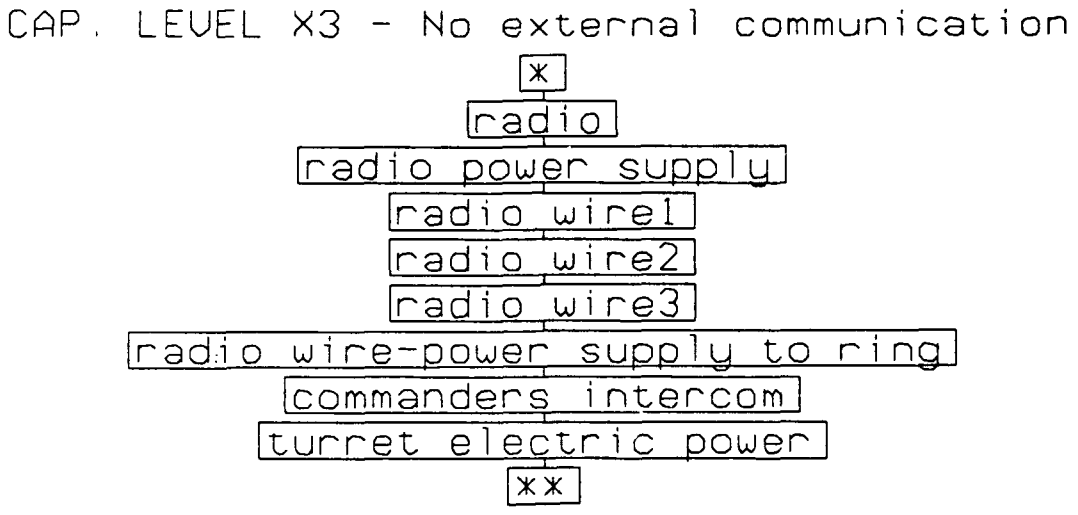

Figure A-20. Fault tree for no external communication.

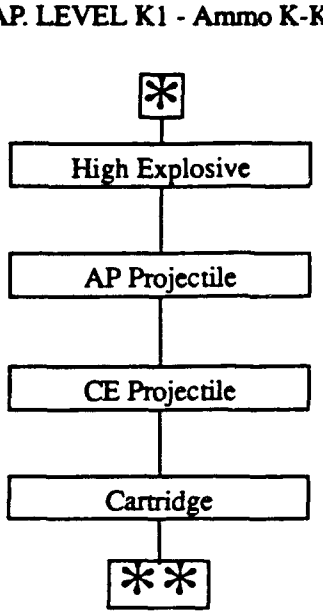

Figure A-21. Fault tree for ammunition K-Kill.

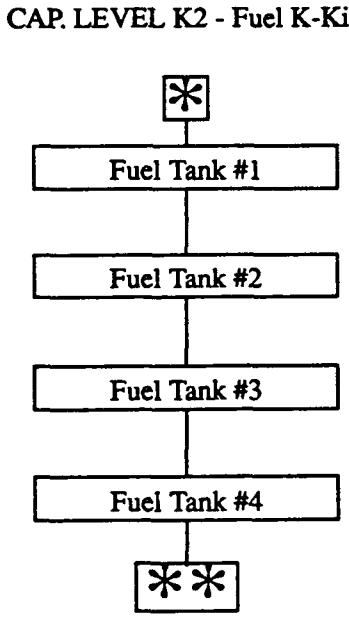

Figure A-22. Fault tree for fuel K-Kill.

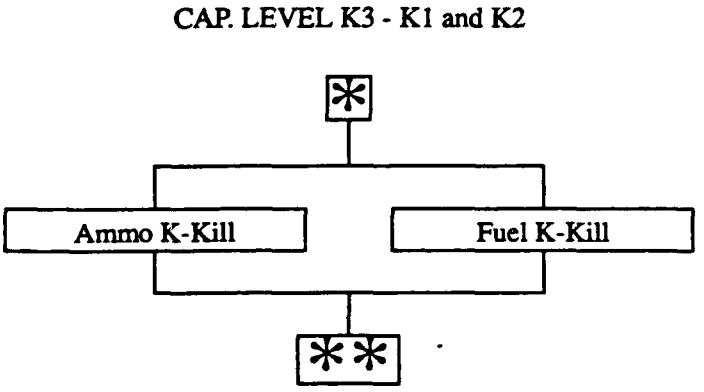

Figure A-23. Fault tree for ammo and fuel K-Kill.

APPENDIX B:

BAR CHARTS AND CELL PLOTS

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This appendix contains selected bar charts and cell plots which are used to illustrate results of this analysis. Figure B-1 is a plot of the DAL-like aggregated PDS and the DAL LOF values vs. range for the marginal overmatch KE penetrator, fully exposed with 2-ft dispersion. The two groups of bars to the left represent the aggregated DS probabilities at 0° and 90° azimuth, respectively. The two on the right show the DAL LOF /F values for 0° and 90°. The color of the bar corresponds to the range with the legend showing the color and range pairs. For each of the bar charts in this section, the independent variable is always represented by different colored bars.

Figures B-25 to B-28 are cell plots of selected results. For Figure B-25, the three DS F capability levels and the DAL F LOF values are shown for all four bullets, at 0° azimuth and 1-km range for the KE threats. White cells correspond to zero probability, and red represent a probability of 1.0. The color scale is shown on the lower right hand corner of the figure. Figure B-26 shows DS and DAL M values for the same set of initial conditions. Figure B-27 shows the DS aggregated M in column one and the DAL M LOF values in column two for all four threats, at 90° azimuth and 1-km range for the KEs. Figure B-28 shows the DS aggregated F in column one and the DAL F LOF values in column two for the same set of initial conditions.

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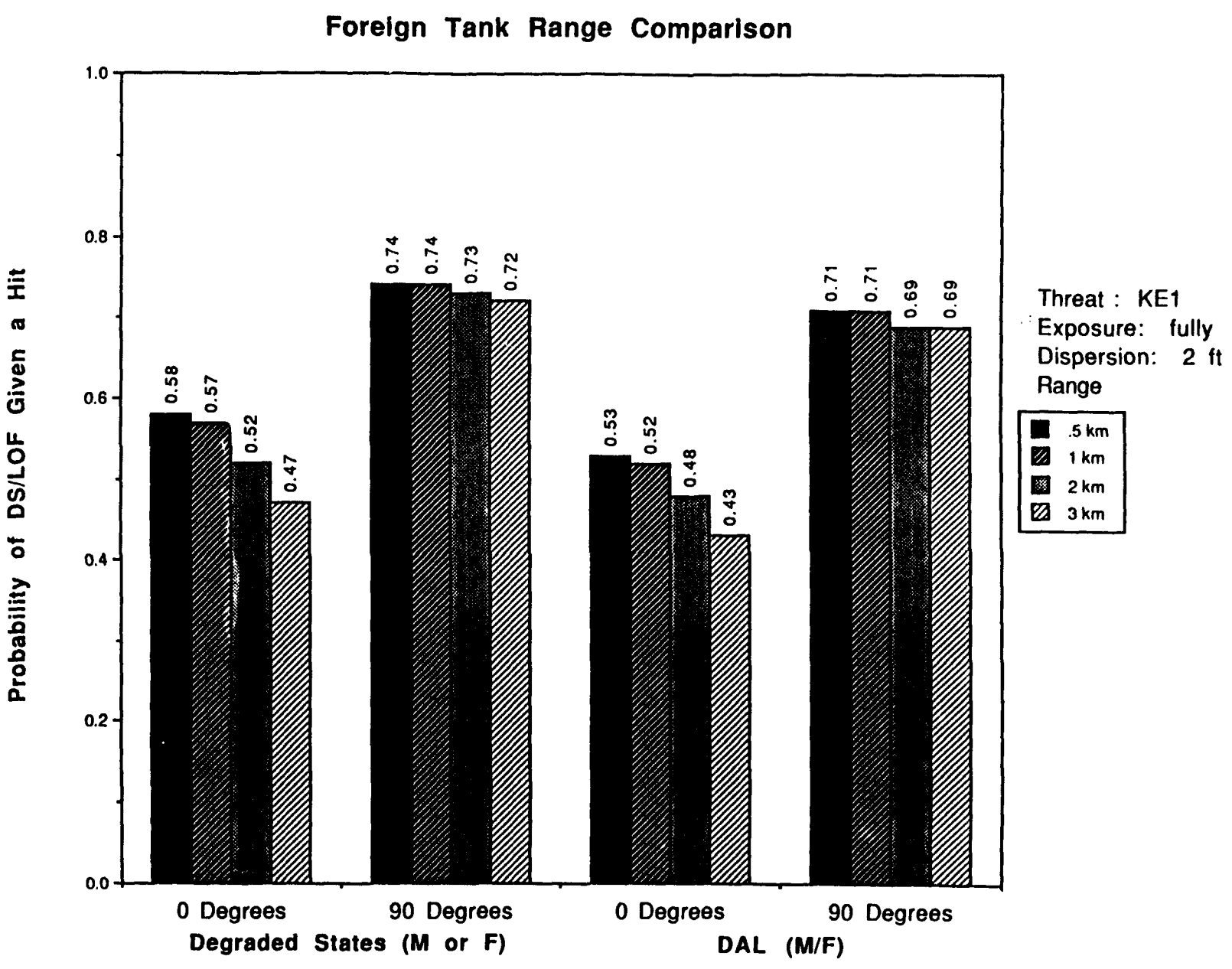

Figure B-1. Results vs. range for KE1, fully exposed.

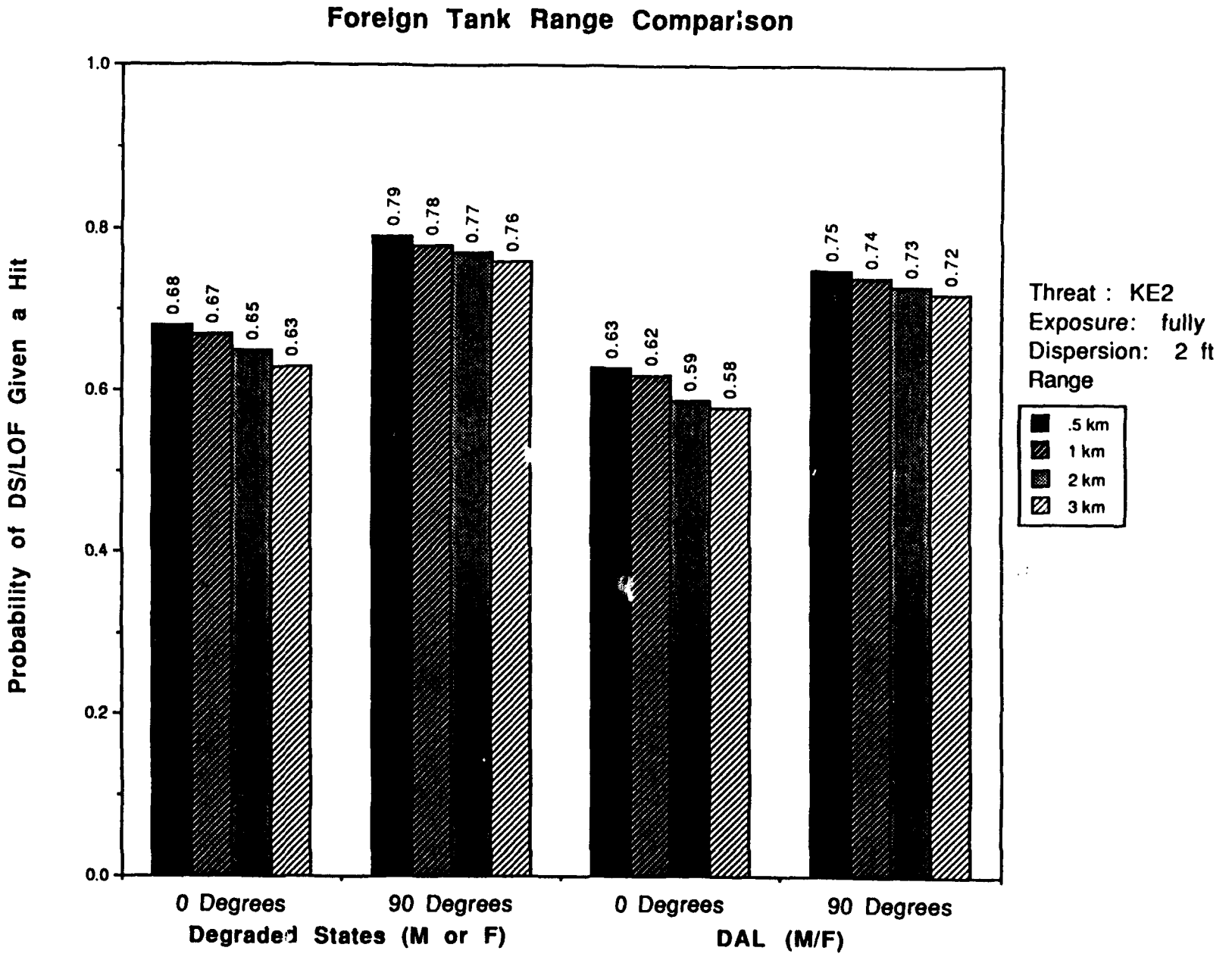

Figure B-2. Results vs. range for KE1, fully exposed.

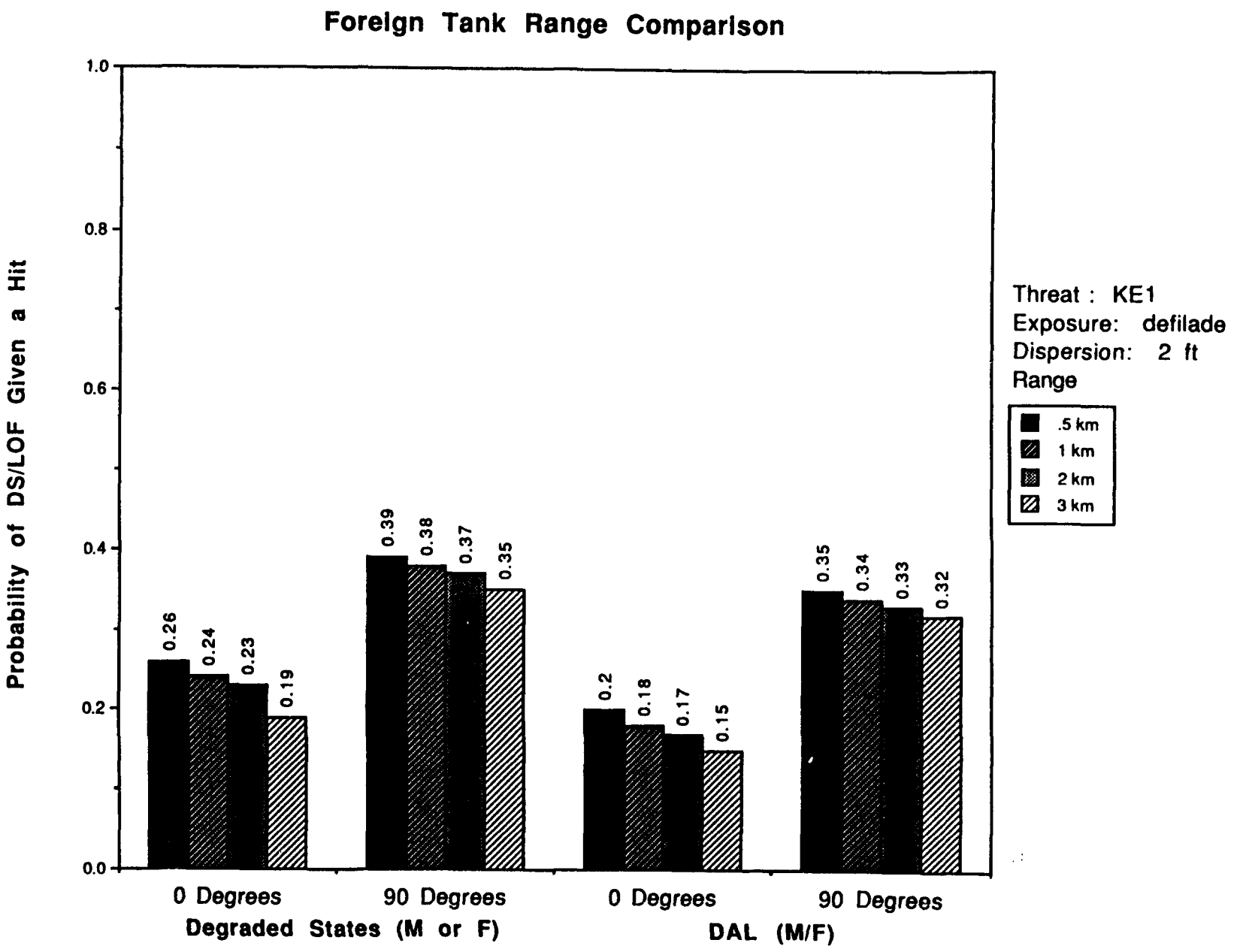

Figure B-3. Results vs. range for KE1, hull defilade.

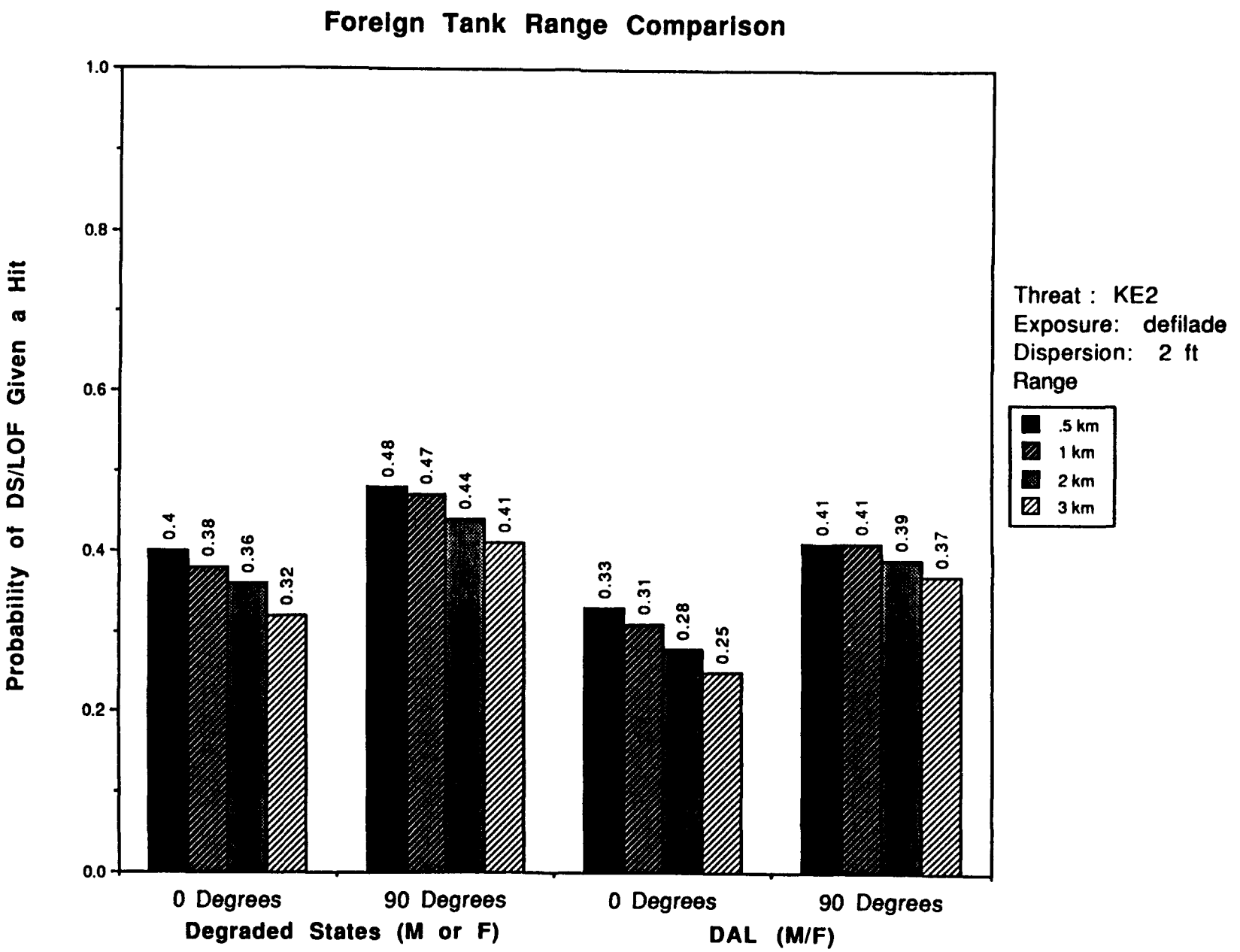

Figure B-4. Results vs. range for KE2, hull defilade.

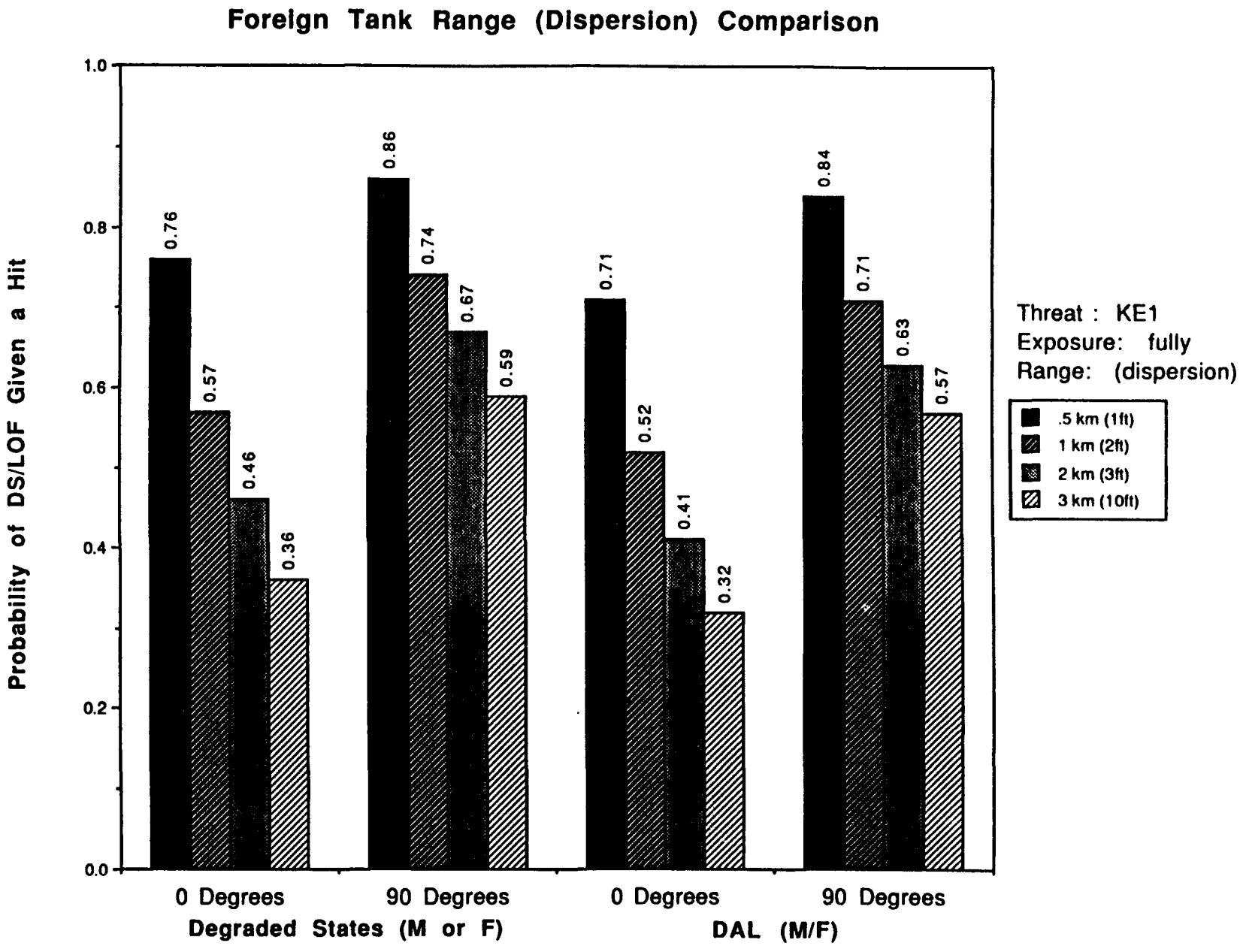

Figure B-5. Results vs. range/dispersion for KE1, fully exposed.

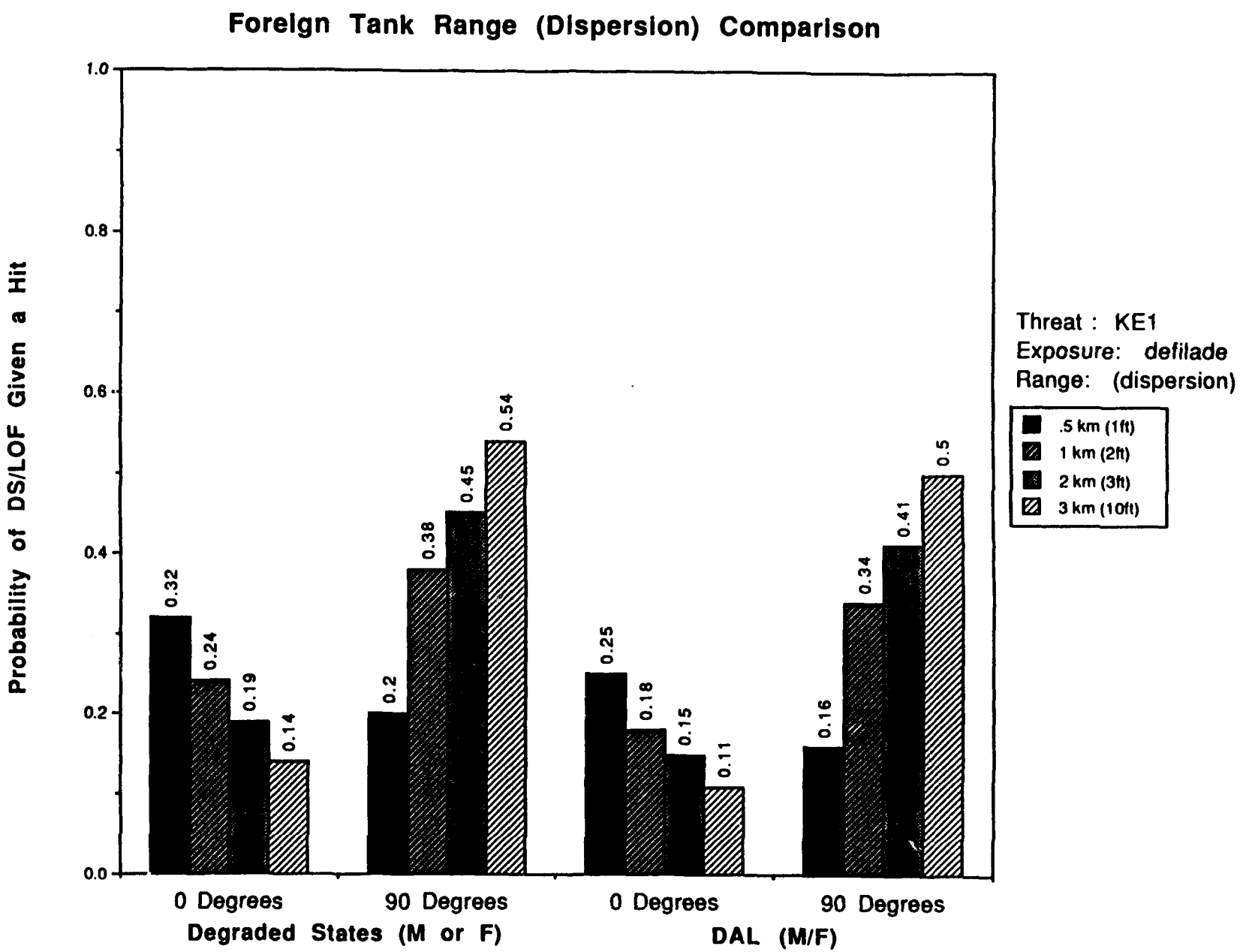

Figure B-6. Results vs. range/dispersion for KE2, fully exposed.

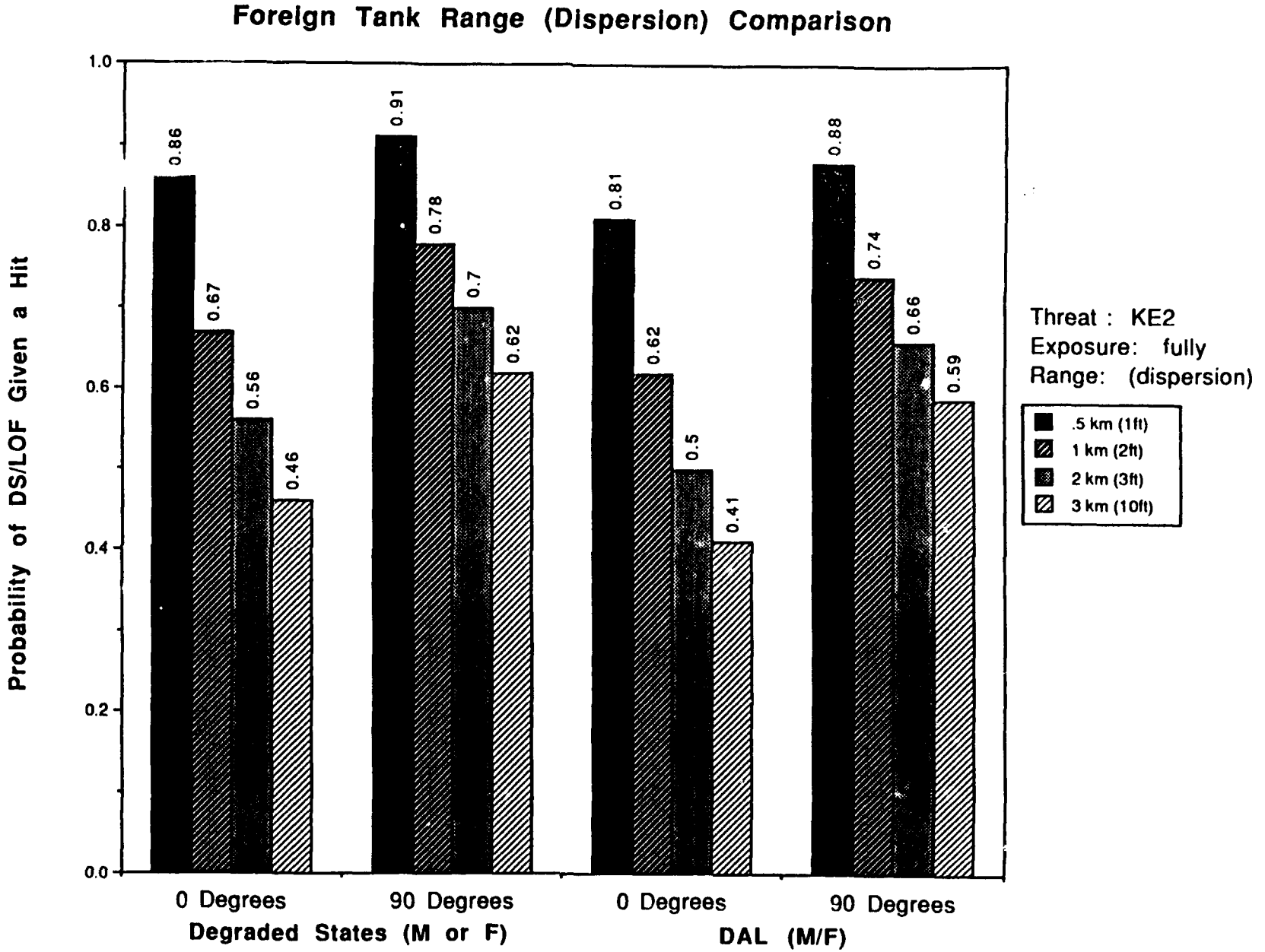

Figure B-7. Results vs. range/dispersion for KE1, hull defilade.

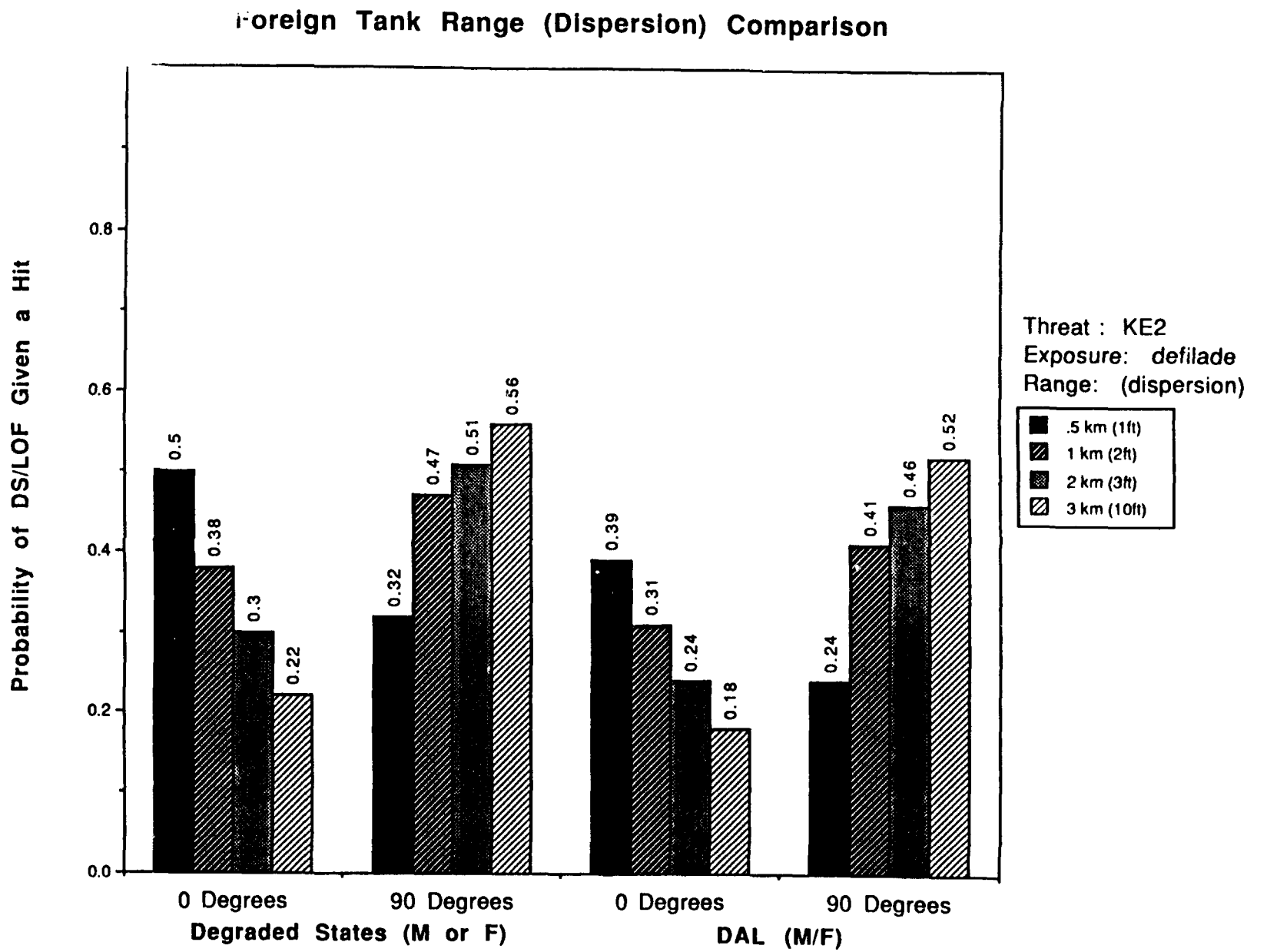

Figure B-8. Results vs. range/dispersion for KE2, hull defilade.

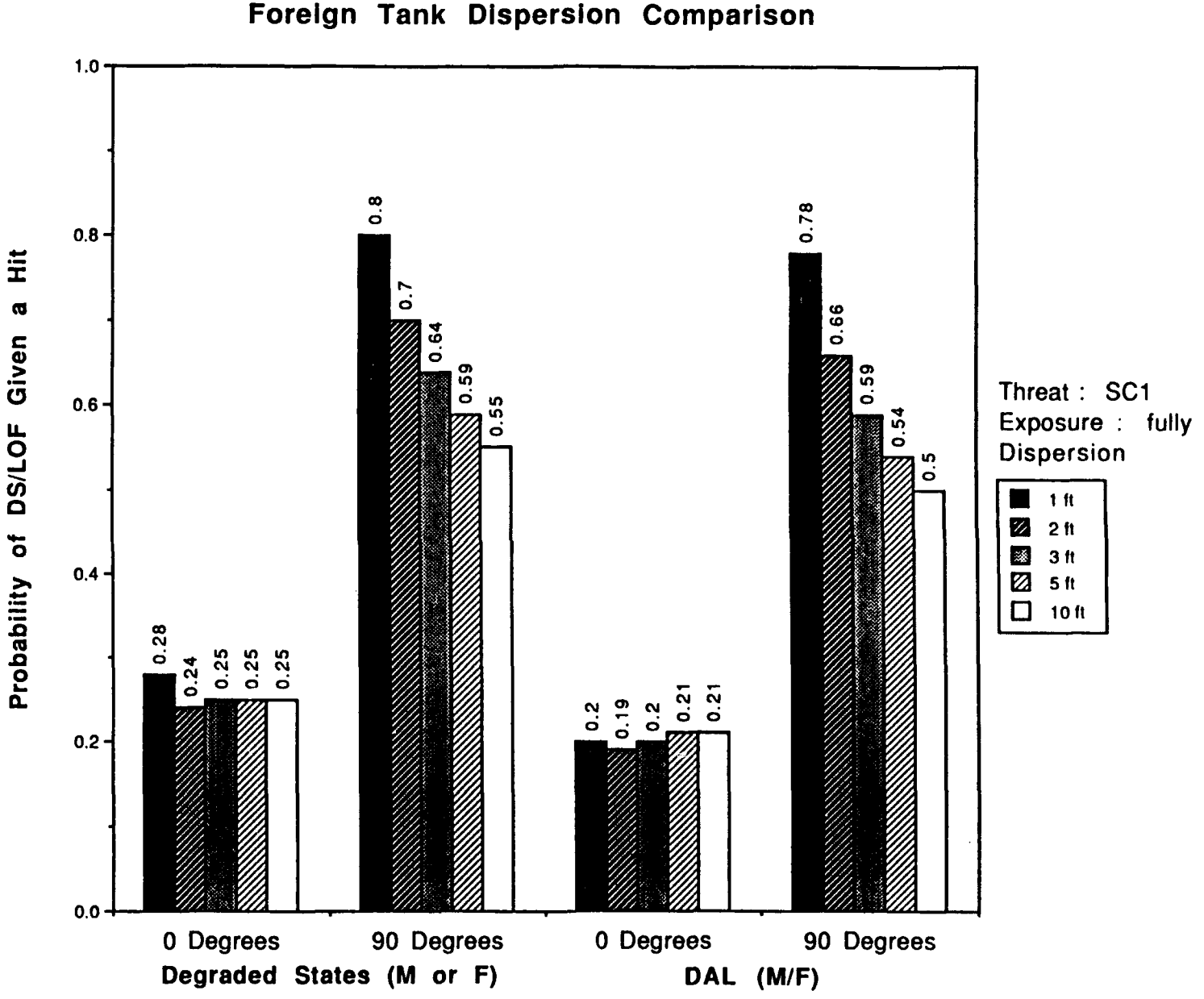

Figure B-9. Results vs. dispersion for SC1, fully exposed.

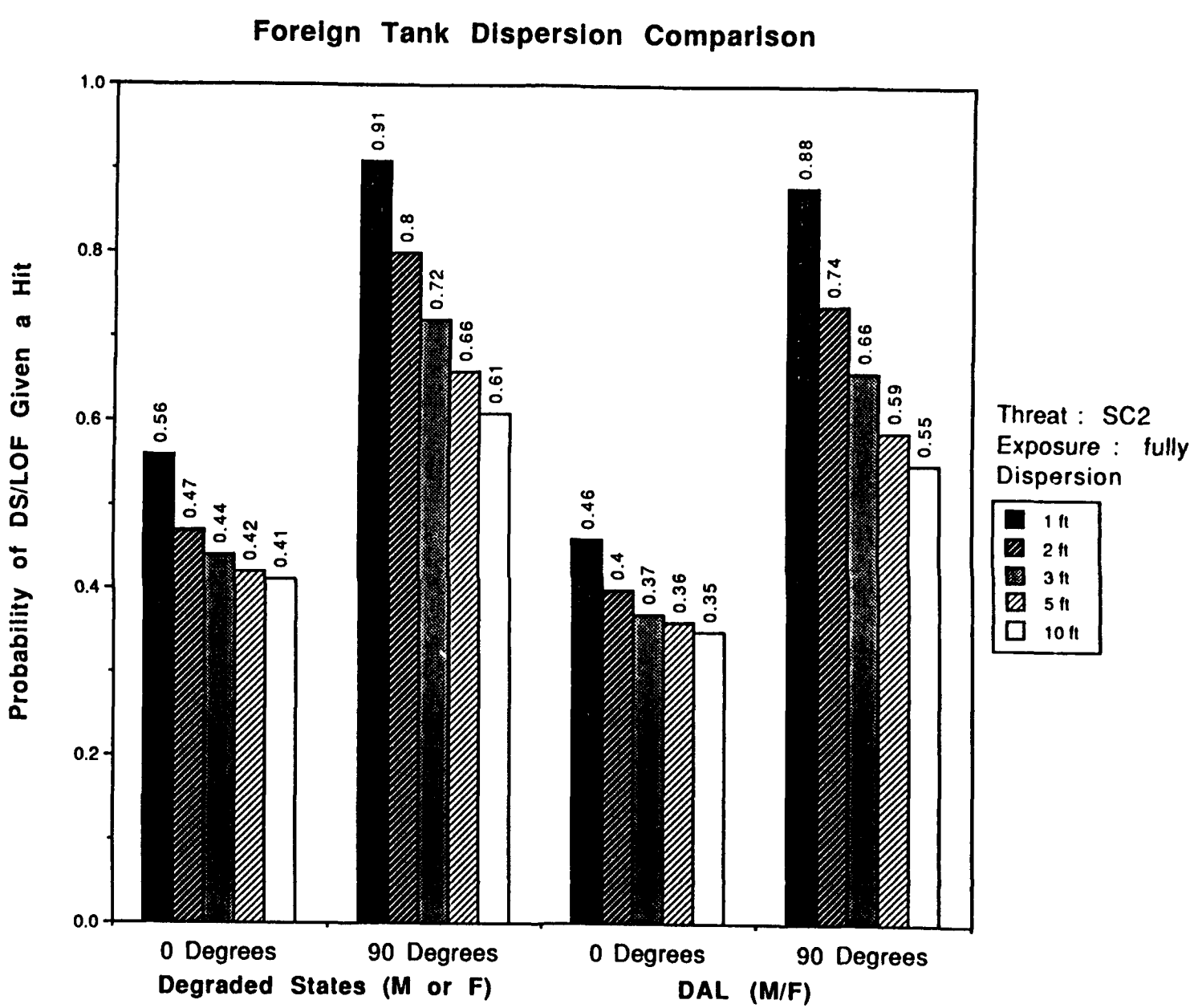

Figure B-10. Results vs. dispersion for SC2, fully exposed.

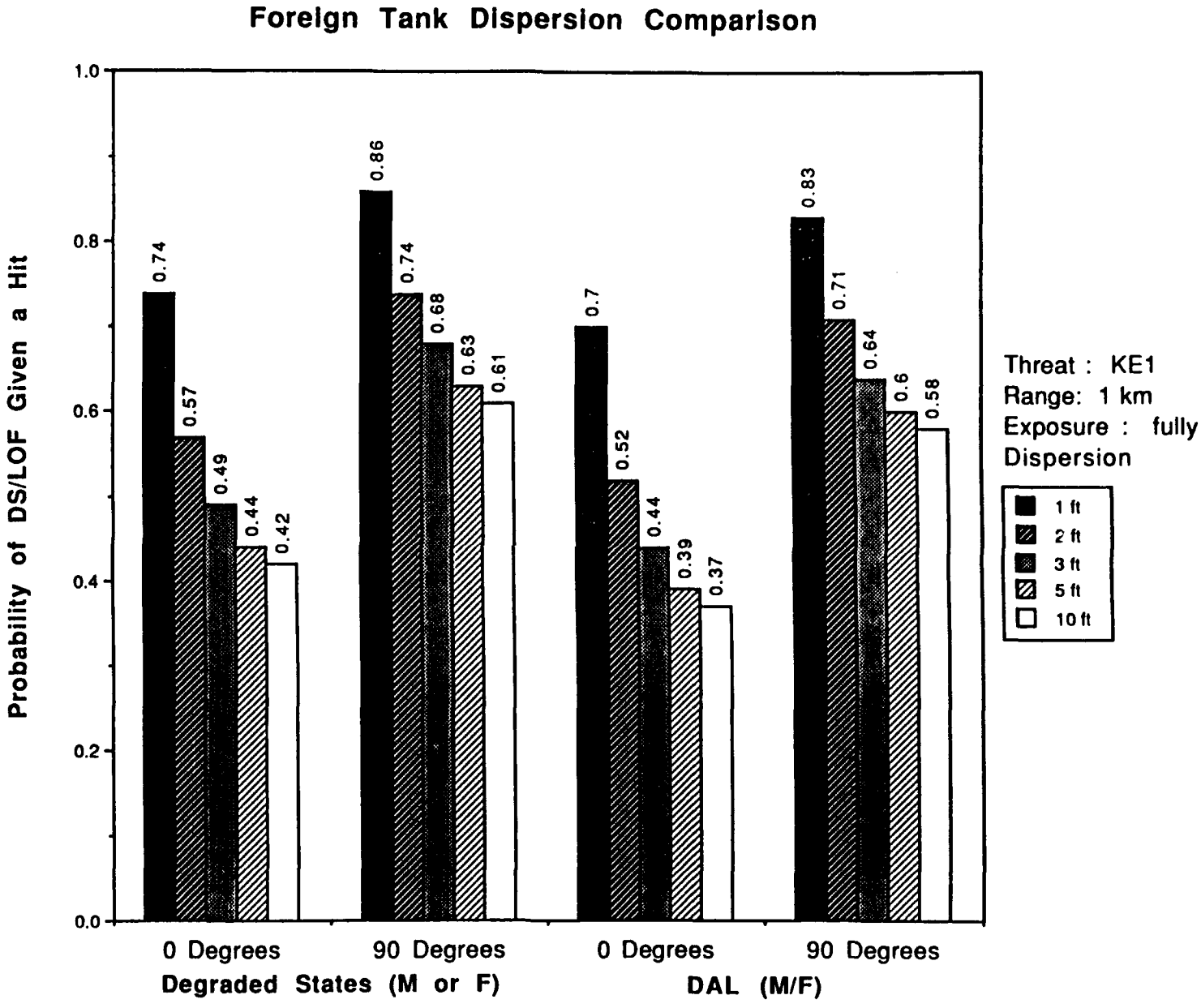

Figure B-11. Results vs. dispersion for KE1, fully exposed.

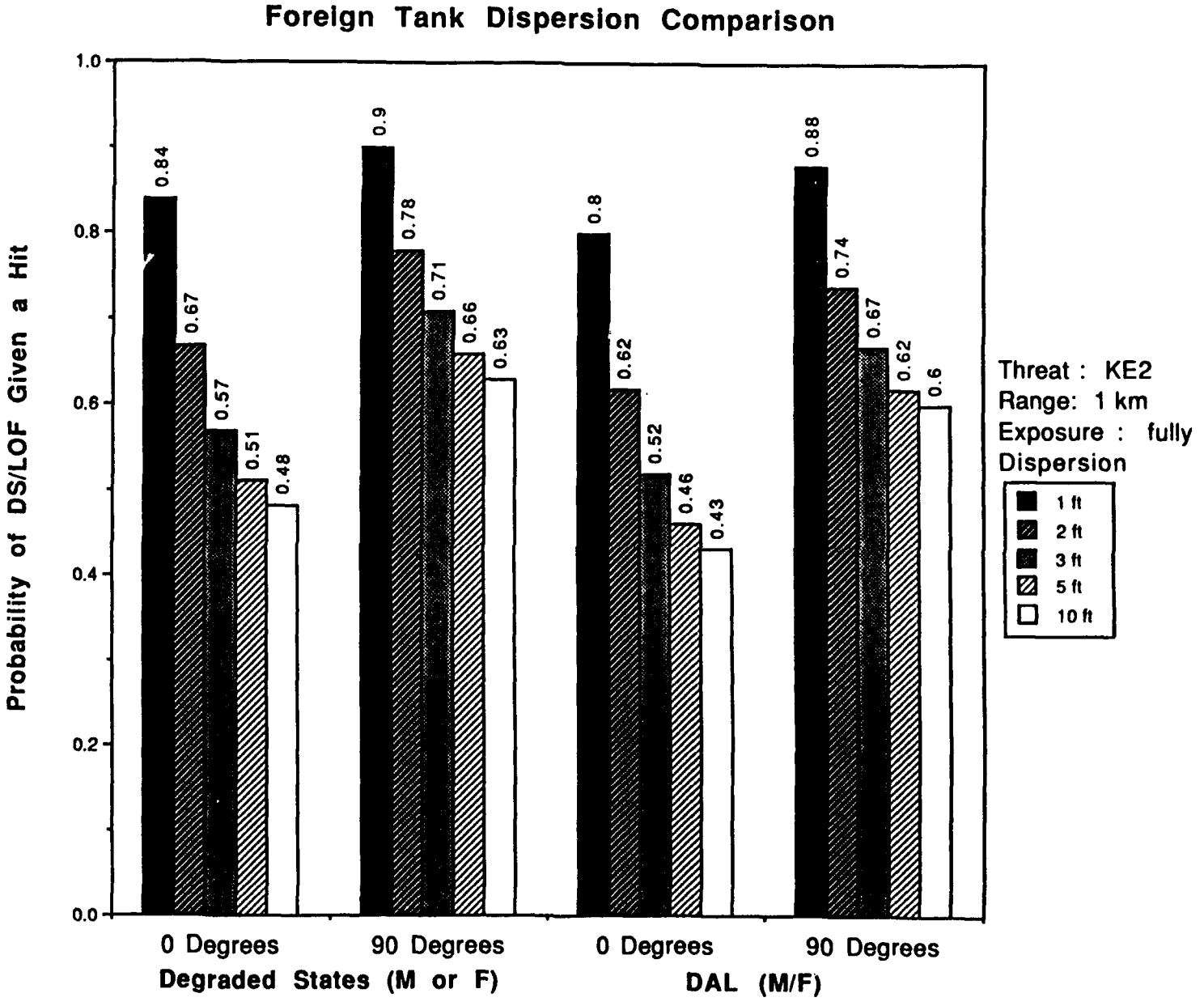

Figure B-12. Results vs. dispersion for KE2, fully exposed.

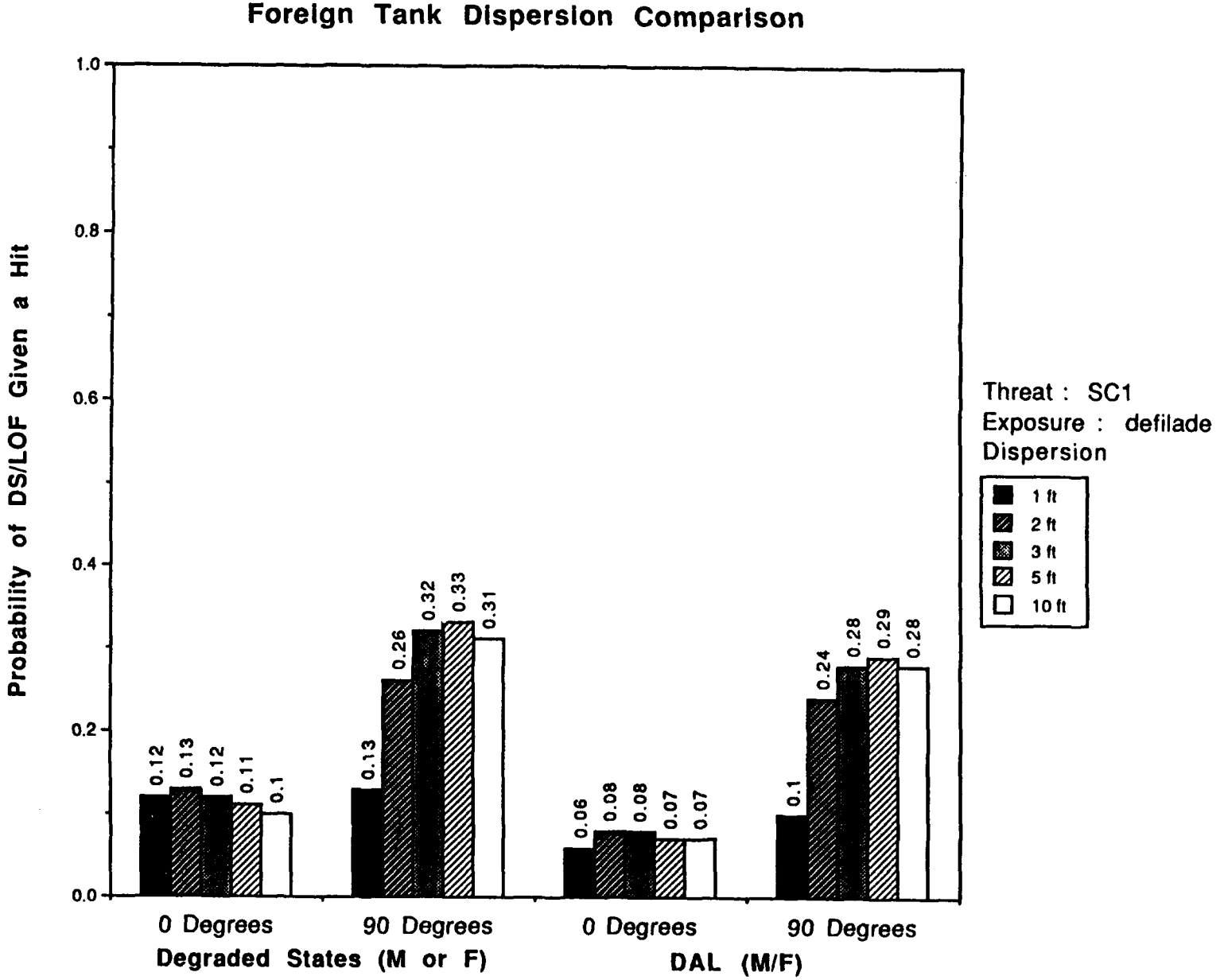

Figure B-13. Results vs. dispersion for SC1, hull defilade.

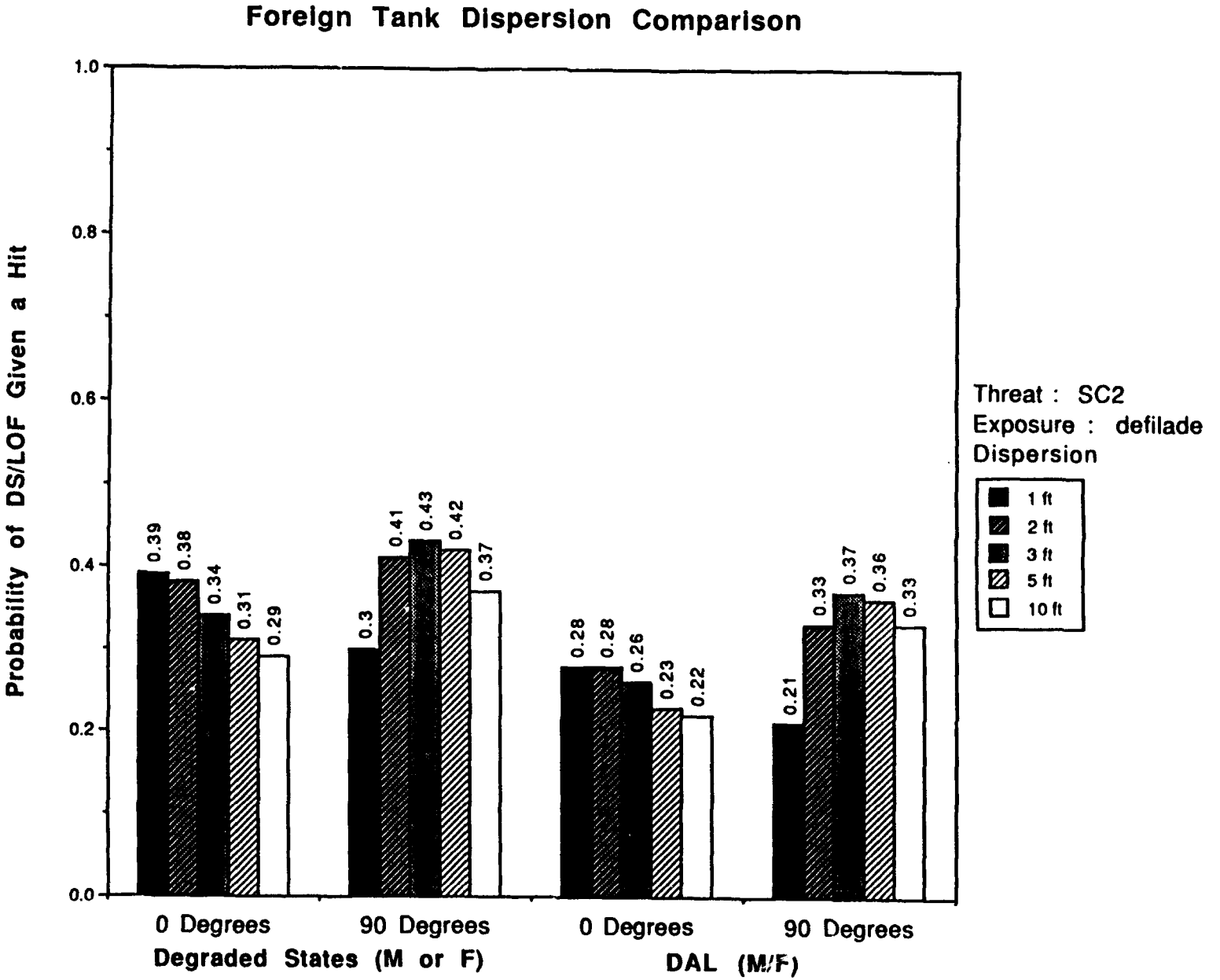

Figure B-14. Results vs. dispersion for SC2, hull defilade.

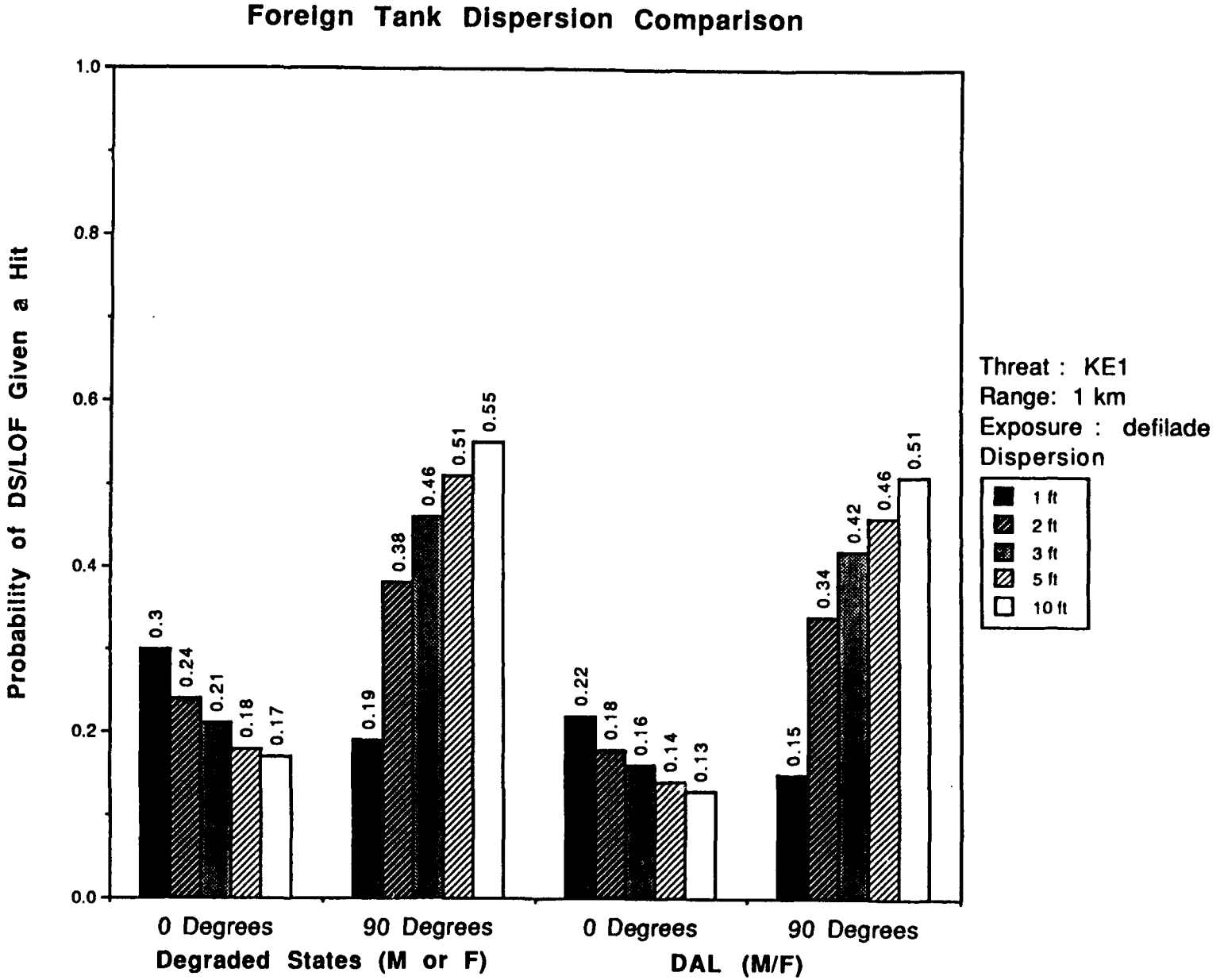

Figure B-15. Results vs. dispersion for KE1, hull defilade.

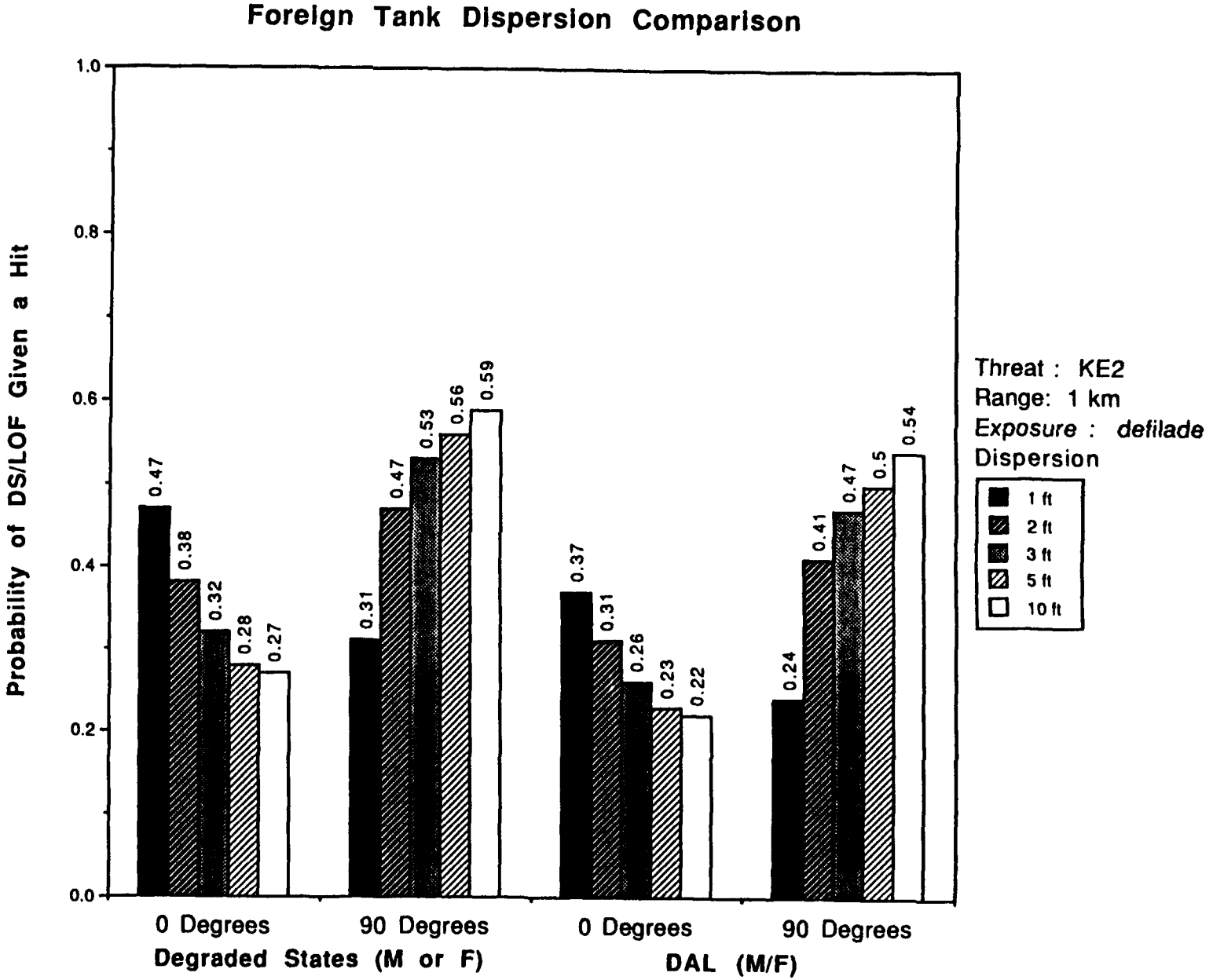

Figure B-16. Results vs. dispersion for KE2, hull defilade.

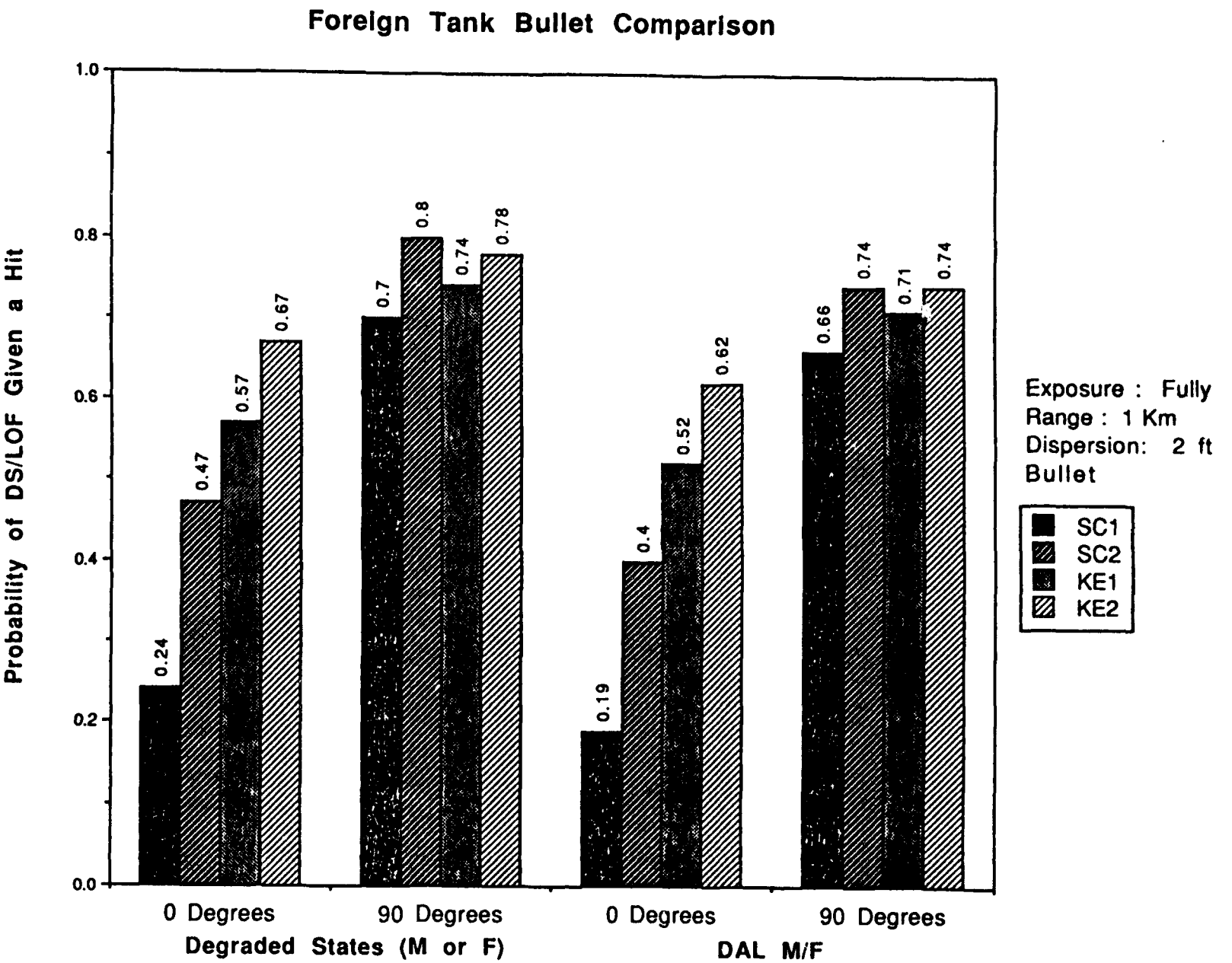

Figure B-17. Results vs. munition for 1-km range, 2-ft dispersion, fully exposed.

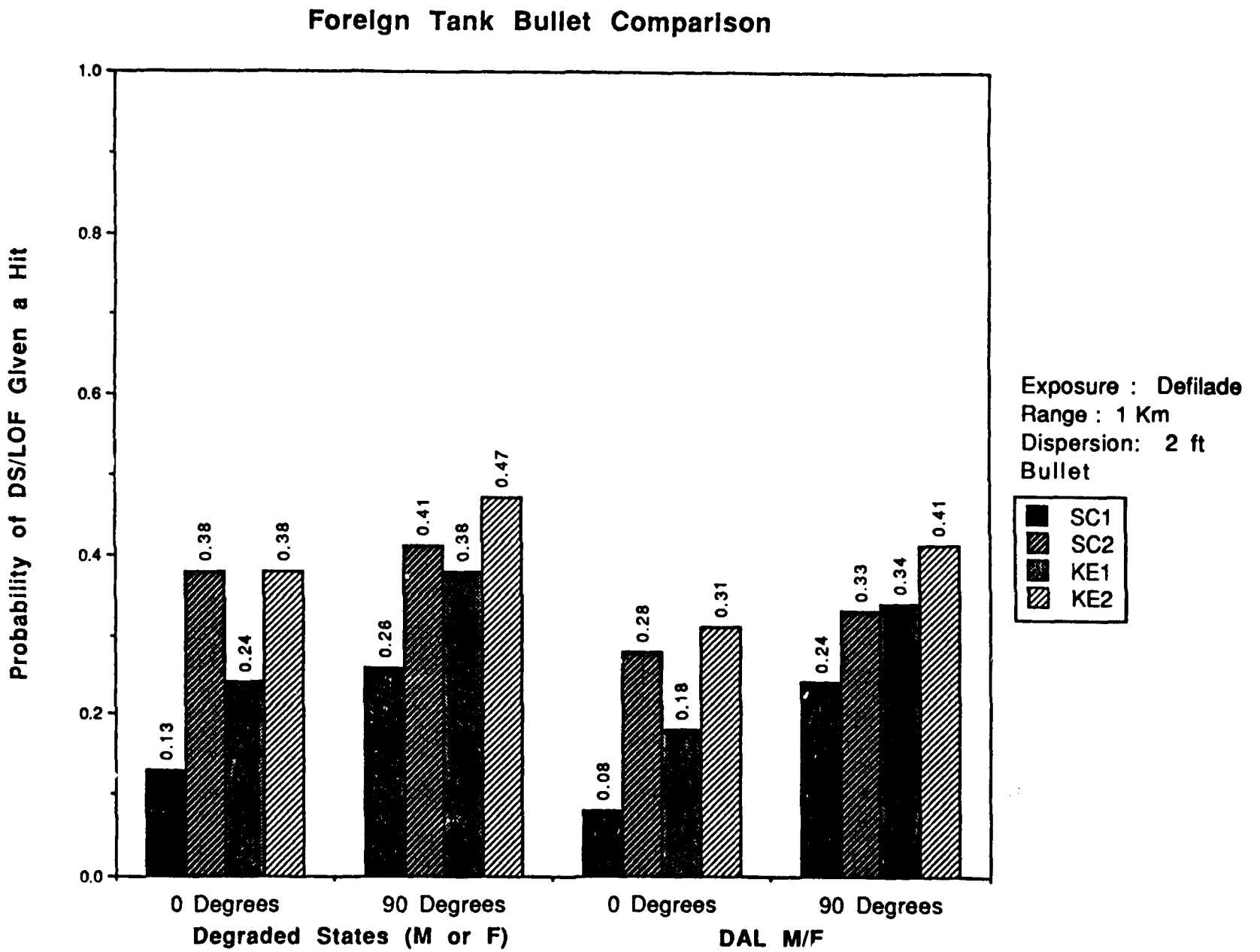

Figure B-18. Results vs. munition for 1-km range, 2-ft dispersion, hull defilade.

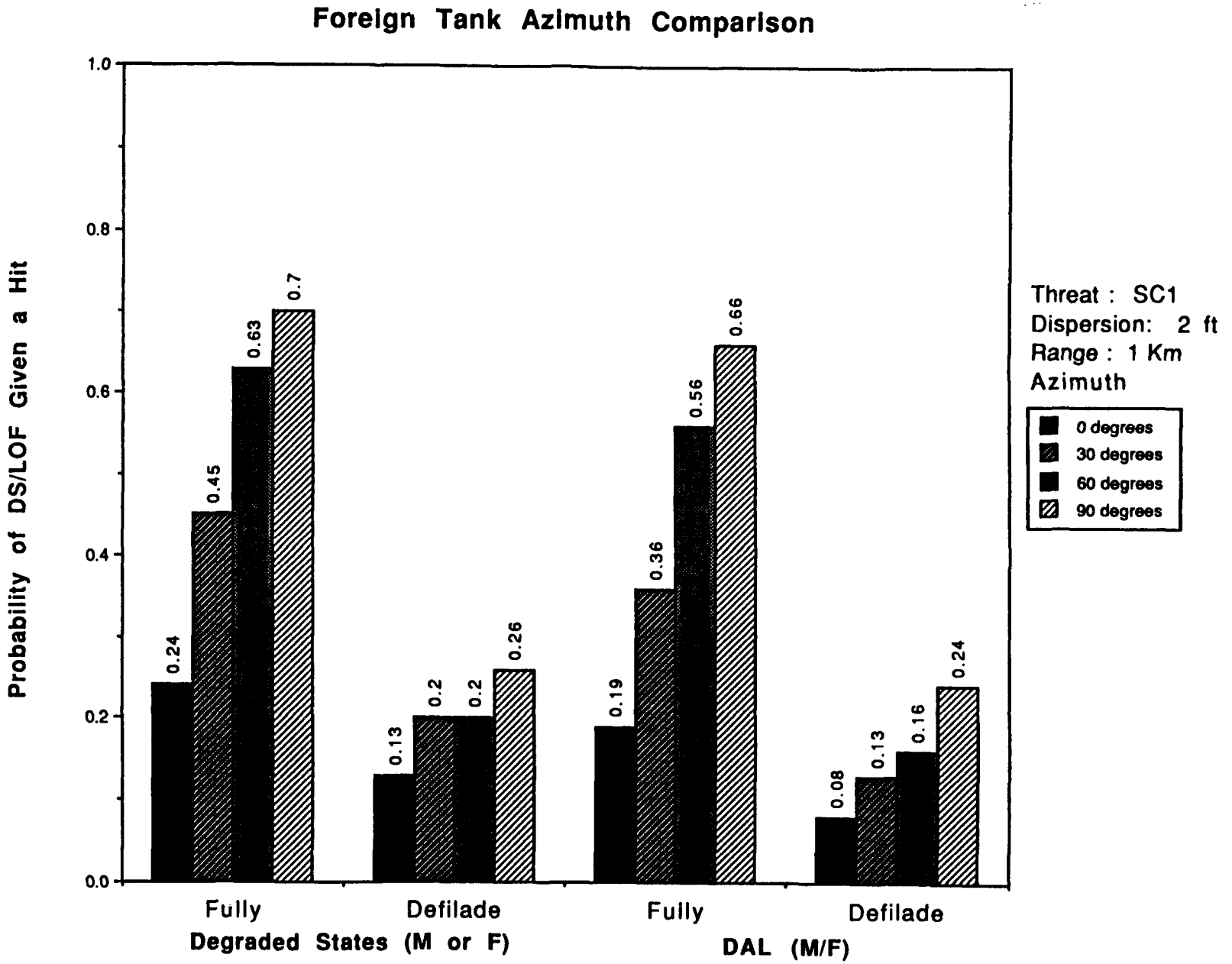

Figure B-19. Results vs. azimuth for SC1.

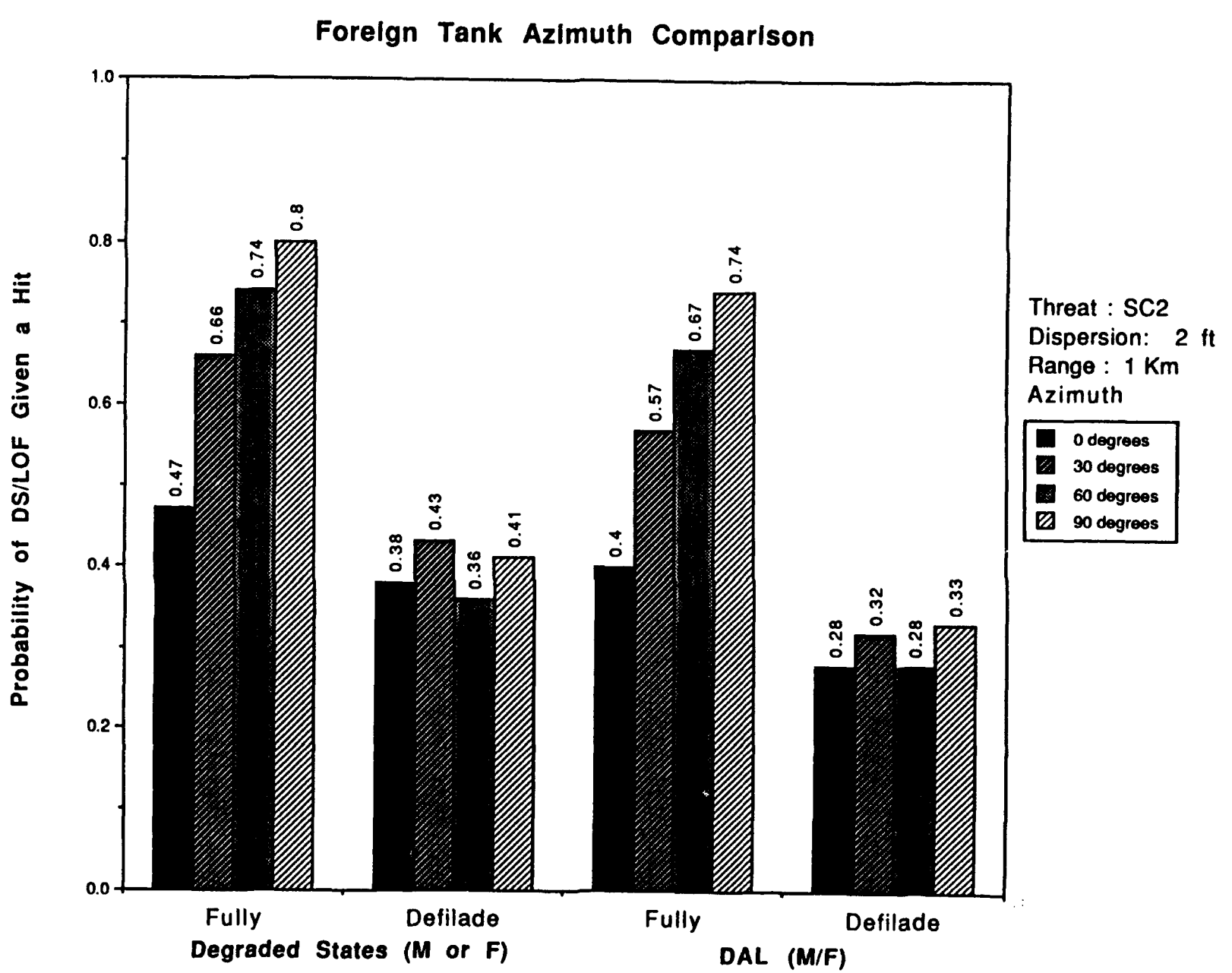

Figure B-20. Results vs. azimuth for SC2.

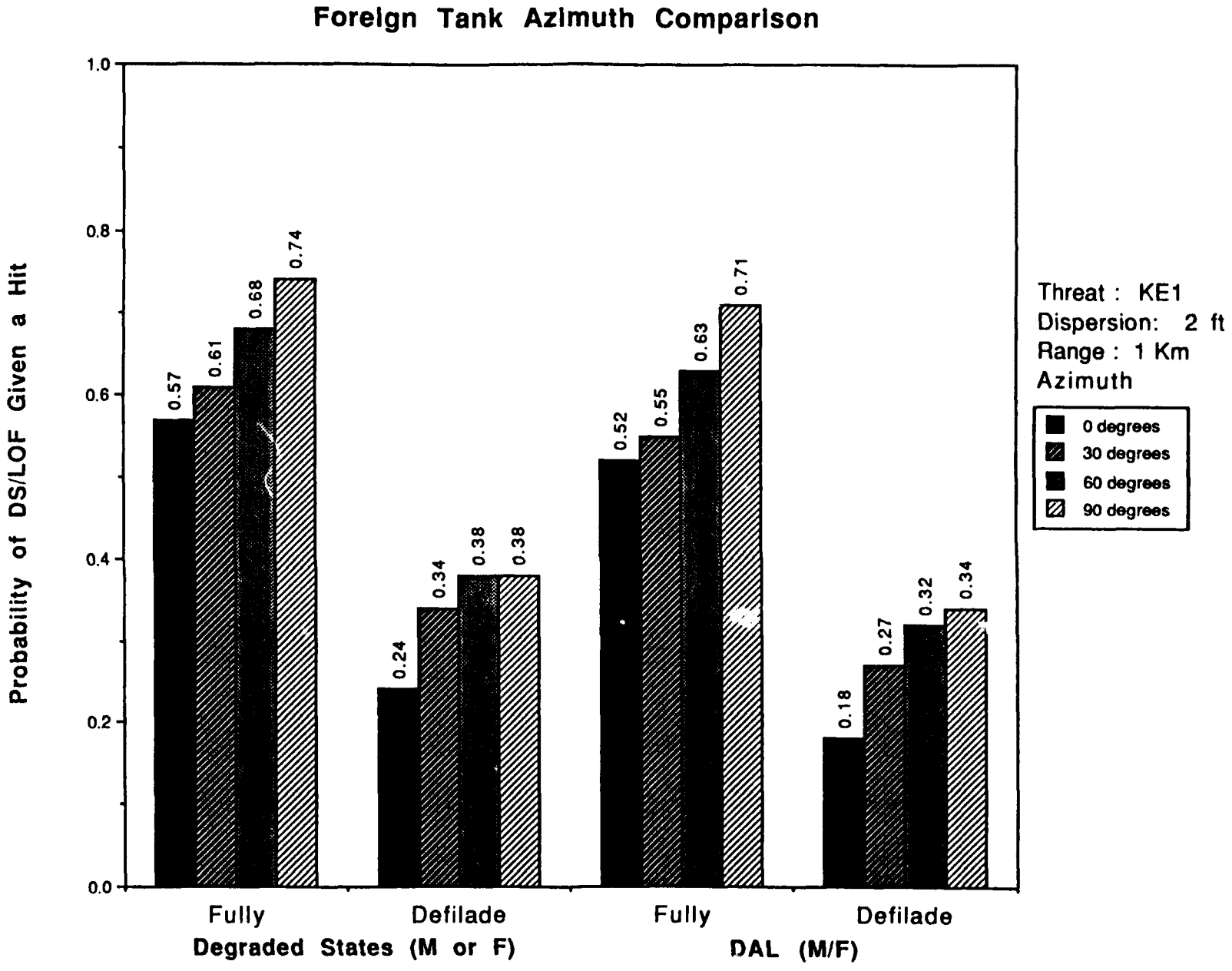

Figure B-21. Results vs. azimuth for KE1.

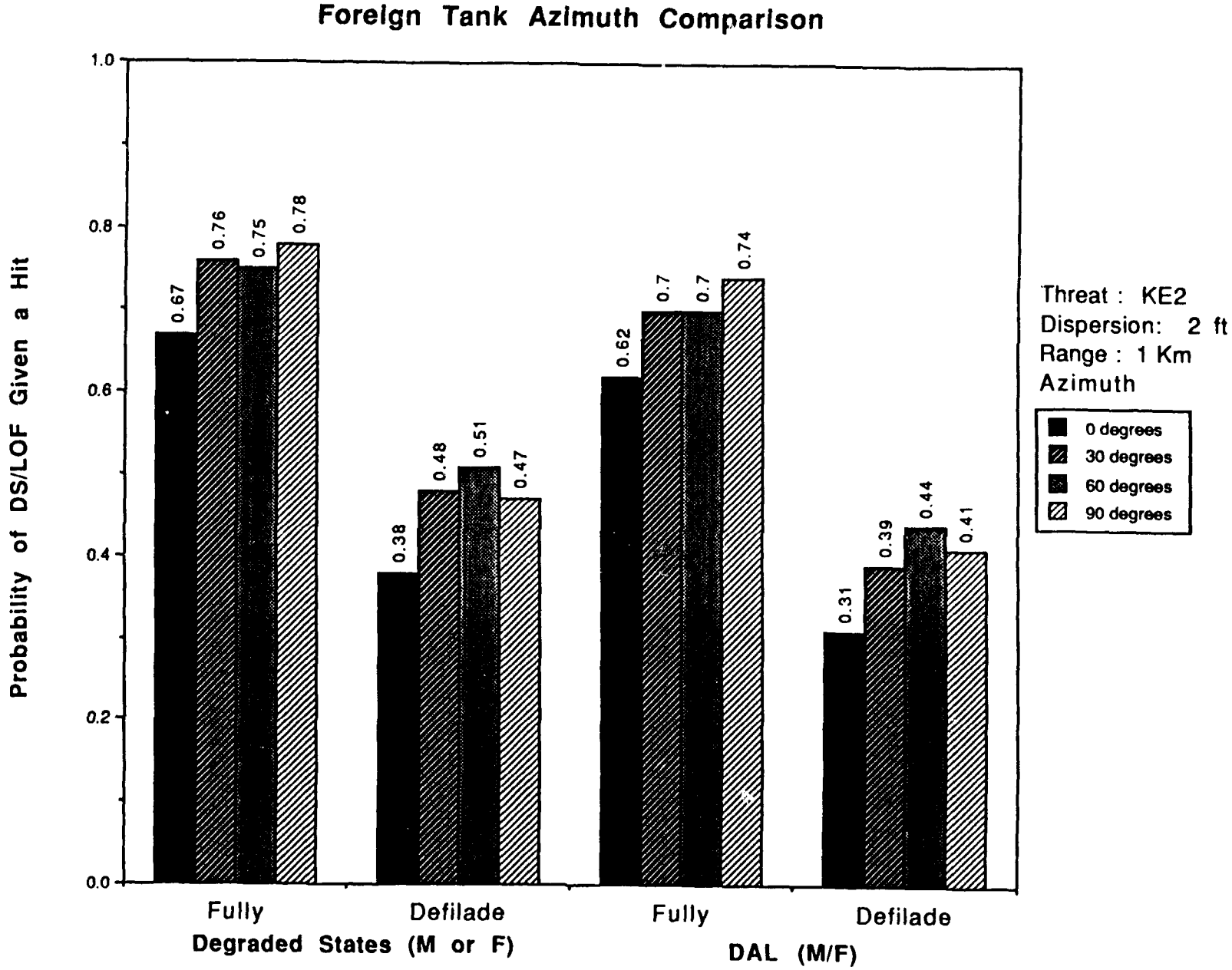

Figure B-22. Results vs. azimuth for KE2.

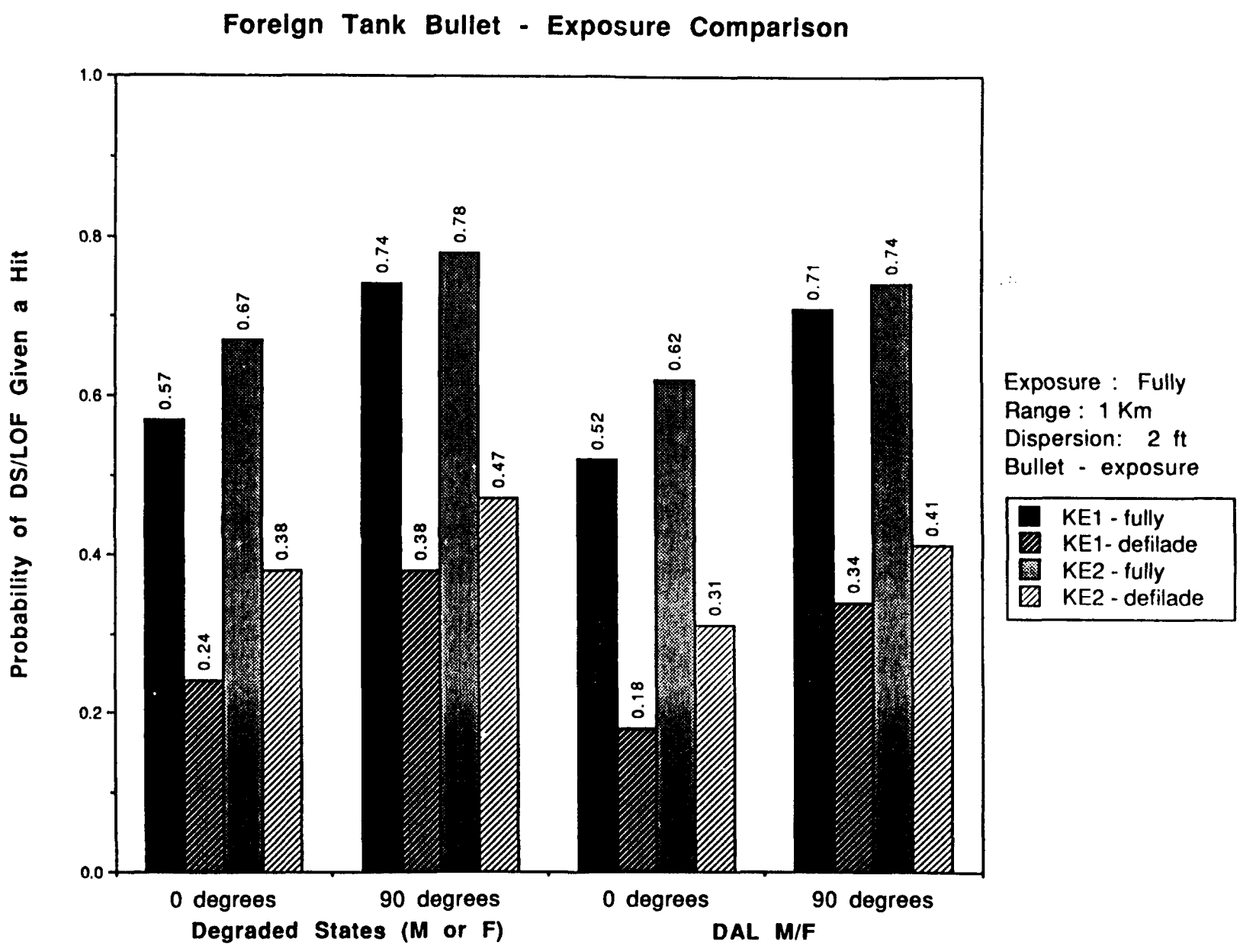

Figure B-23. Results vs. exposure for KE1 and KE2.

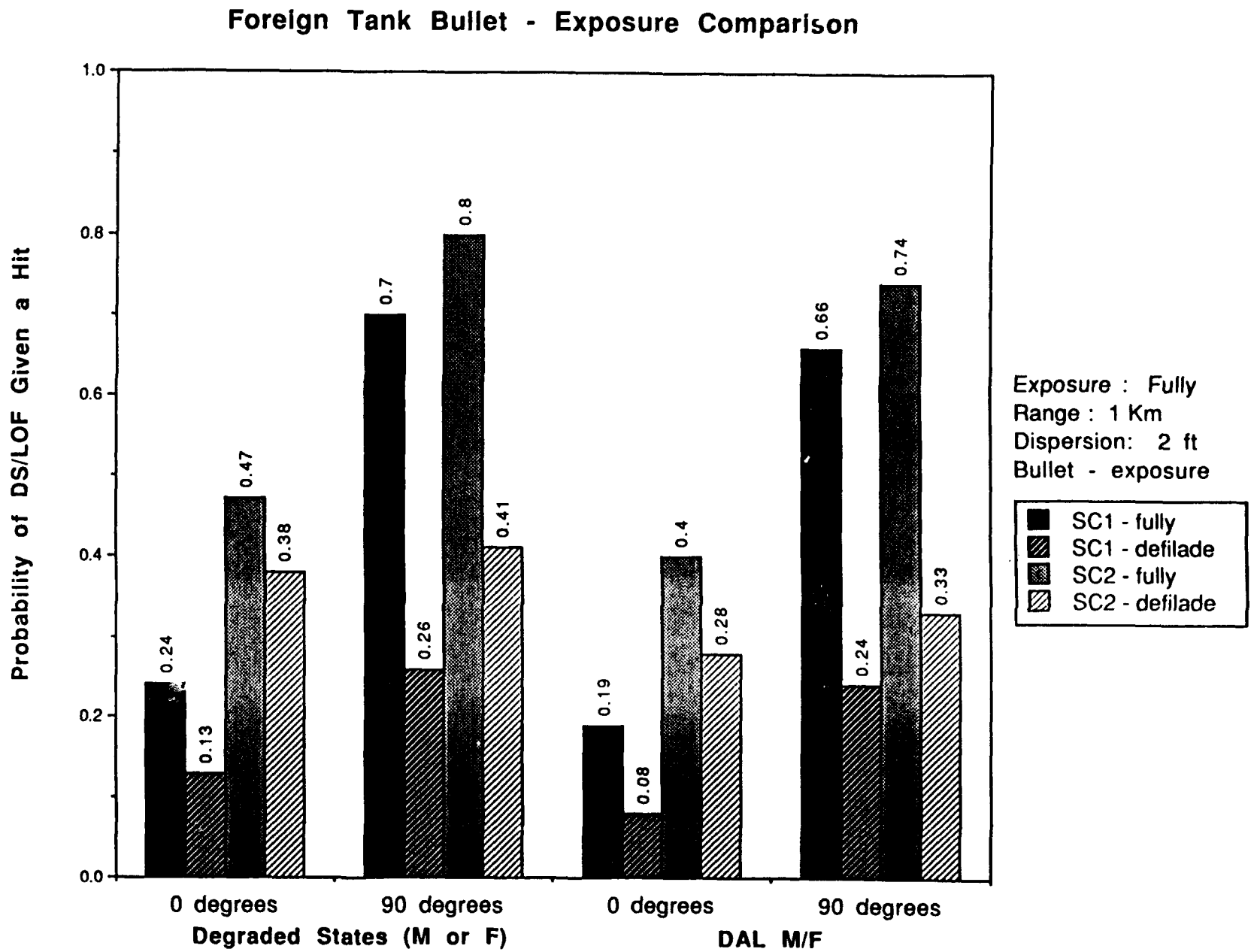

Figure B-24. Results vs. exposure for KE1 and SC2.

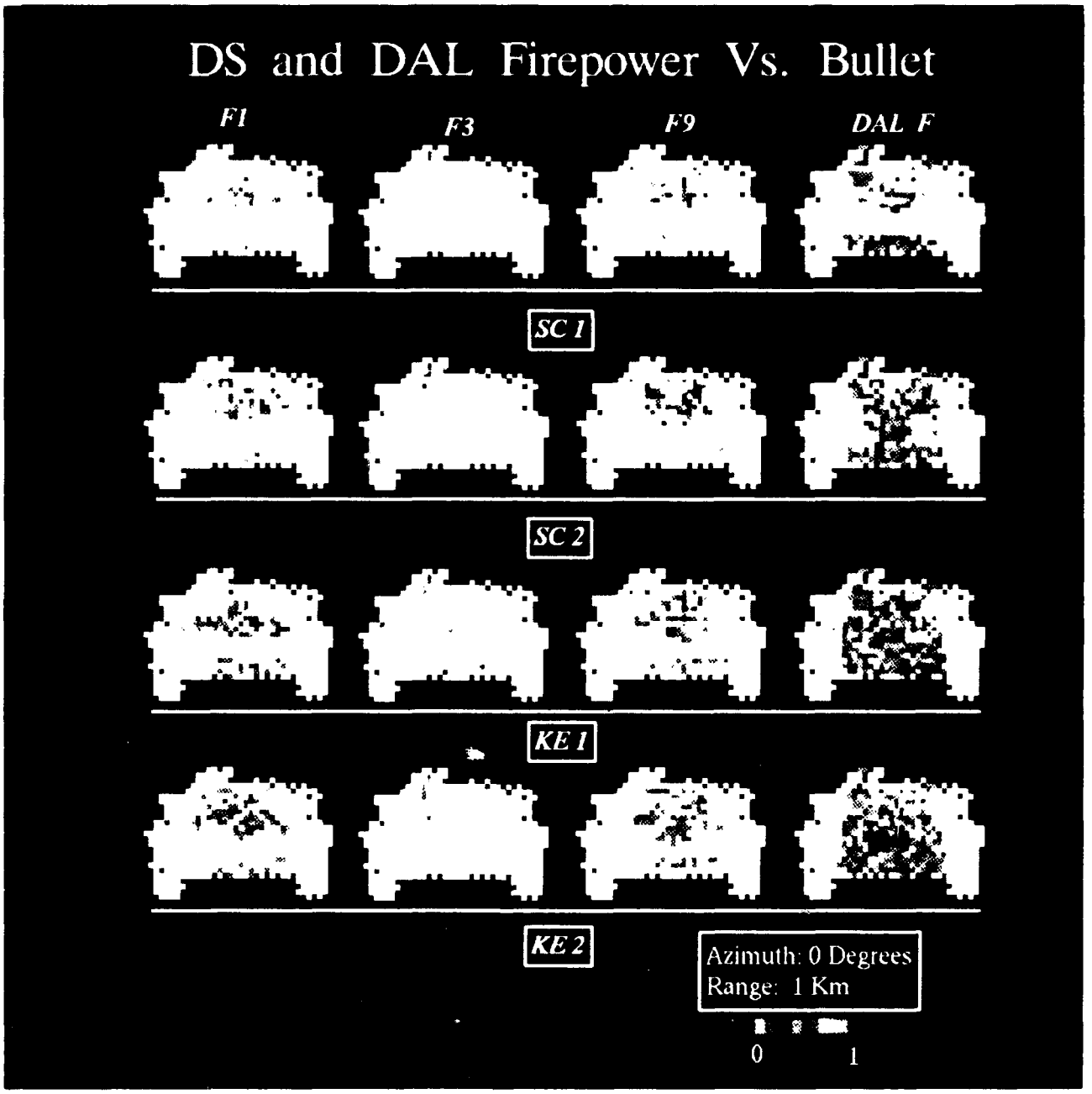

Figure B-25. Degraded states and Damage Assessment List firepower vs. munition.

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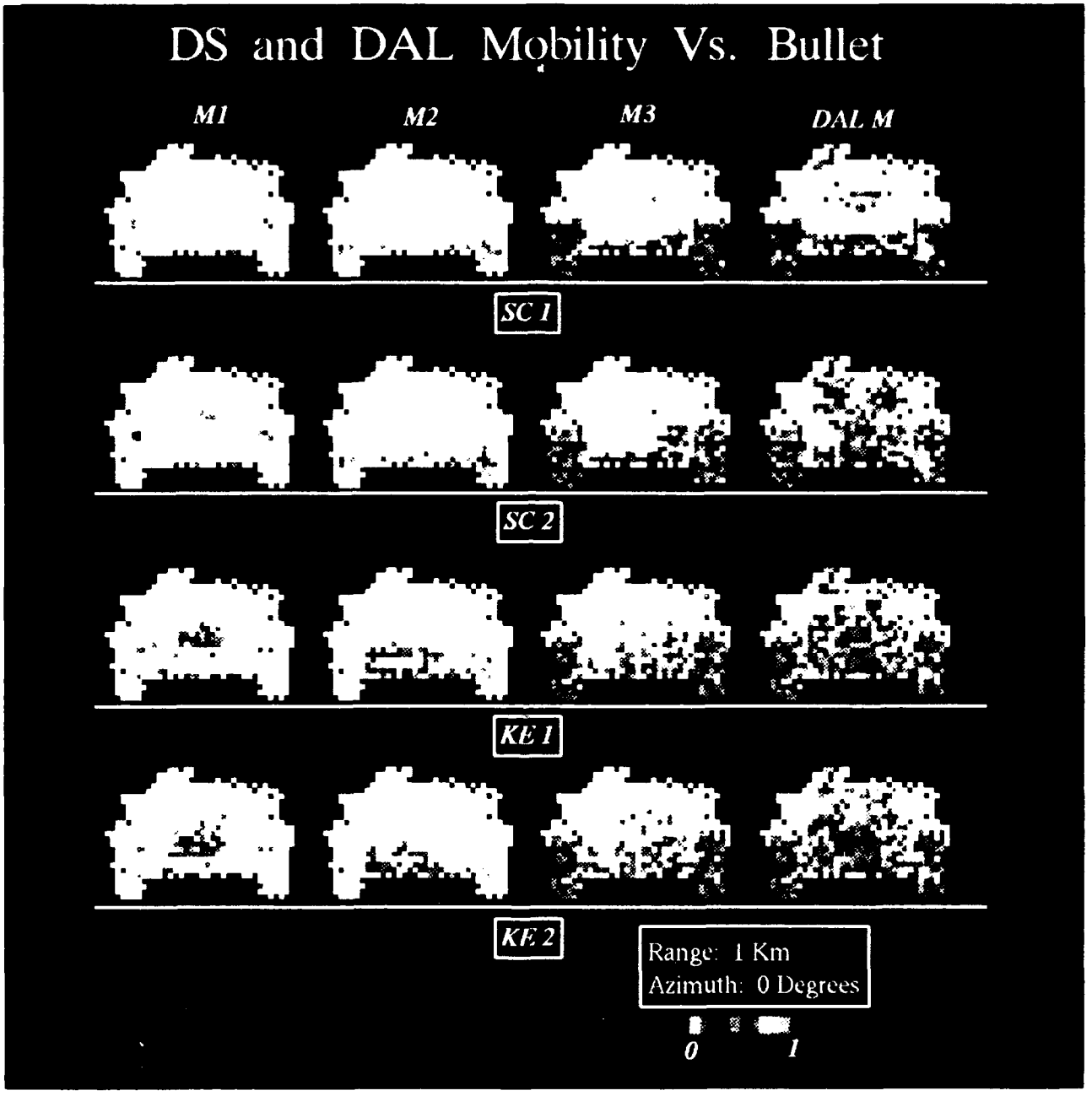

Figure B-26. Degraded states and Damage Assessment List mobility vs. munition.

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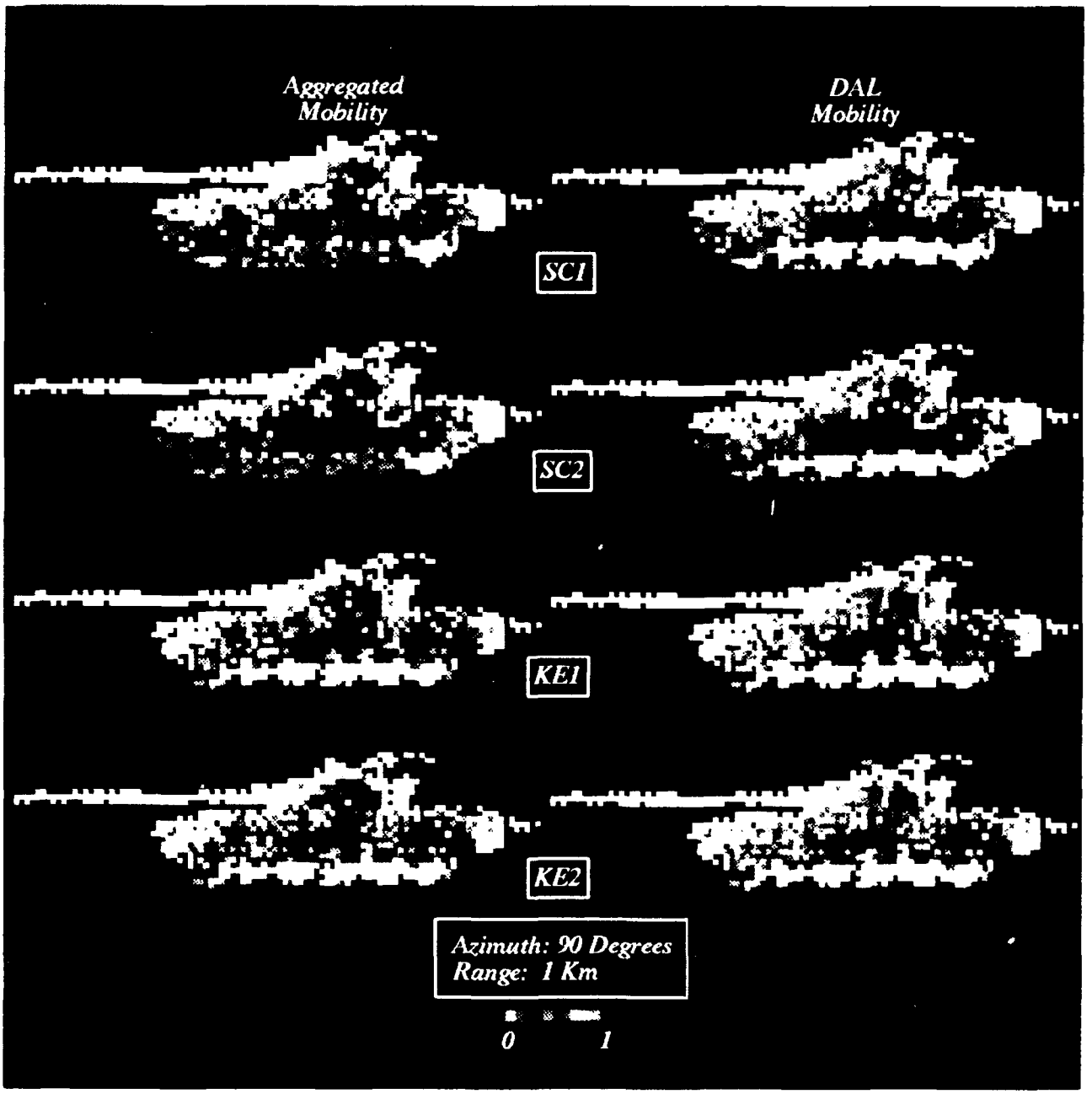

Figure B-27. Aggregated degraded states and Damage Assessment List mobility vs. munition

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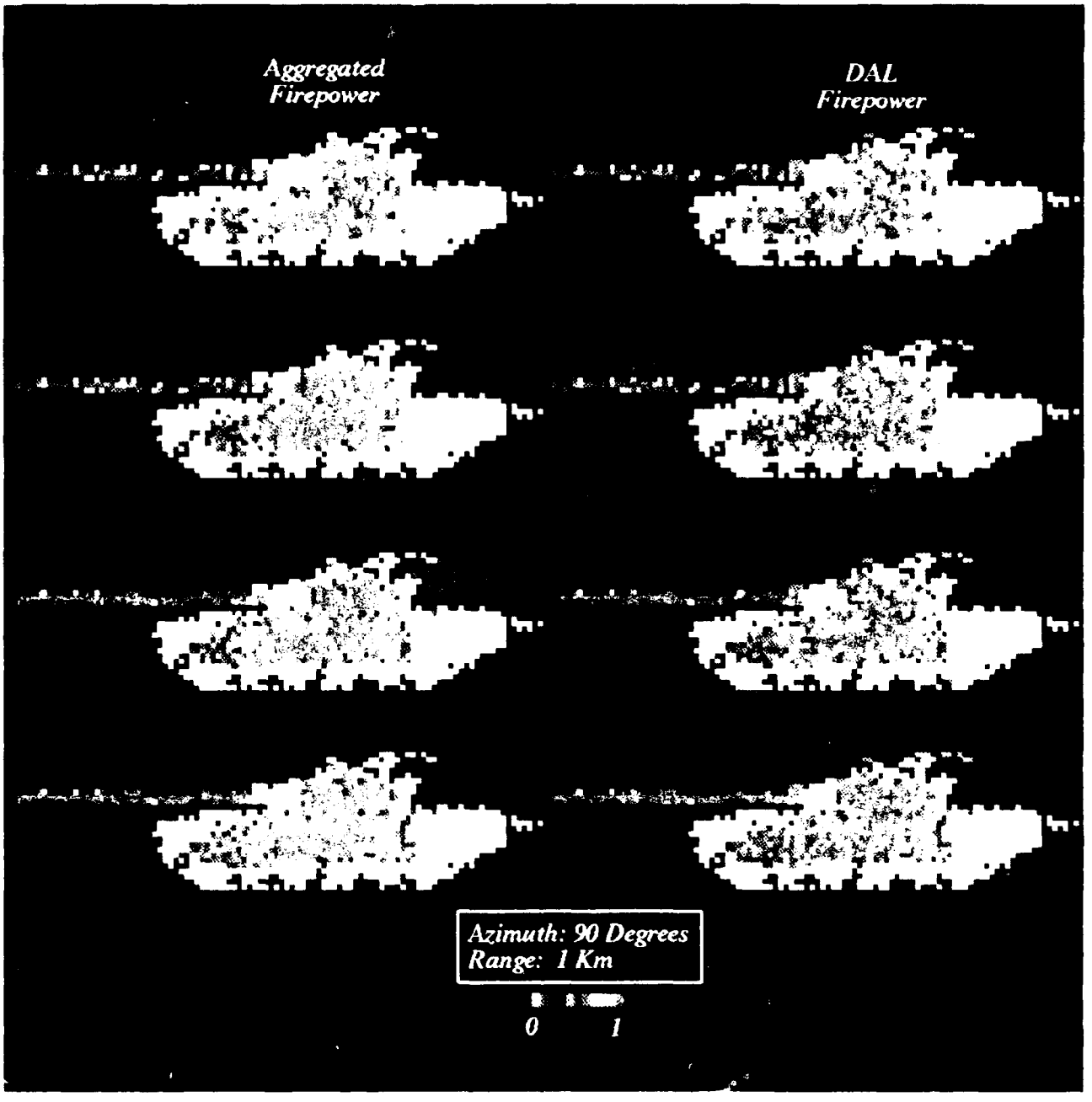

Figure B-28. Aggregated degraded states and Damage Assessment List firepower vs. munition.

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APPENDIX C:

SUMMARY OF RESULTS FOR: DEGRADED STATES CAPABILITY LEVEL PROBABILITIES,
DAMAGE ASSESSMENT LIST LOSS OF FUNCTION VALUES,
AGGREGATED DEGRADED STATES METRICS

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An illustrative set of results are provided in this appendix. Results are presented for:

- all four bullets,
- 0° and 90° azimuth,
- fully exposed and hull defilade,
- 2-ft dispersion.

The complete set of results are available from the authors. Each table contains the capability categories and levels in the first column. The DS probabilities are in the second column, and the DAL LOF values are in the third column. Columns four through six contain the aggregated DS probabilities for the three different types of aggregation.

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Table C-1. Results for SC1, 0°, Fully Exposed, 2 ft

Threat: SC1
Azimuth: 0 Degrees
Exposure: Fully
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.03				
Reduced Speed, Significant	.01				
Total Immobilization	.07				
	.11	.16	.21	.11	.14
• **Firepower**					
Loss of Main Armament	.05				
Increased Time to Fire	0.0				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.04				Operate
	.09	.14	.19	.10	.15
• **Acquisition**					
Reduced Acquisition Capability	.08				
	.08	?	?	?	?
• **Crew**					
Driver	.02				
Commander	.04				
Gunner	.01				
Driver and Commander	.02				
Commander and Gunner	.01				
D, C & G	0.0				
	0.10	?	?	?	?
• **Communications**					
No External Commo	.01				
No Internal Commo					
No External Commo	.04				
	.05	?	?	?	.09
• **K-Kill**					
Ammo K-kill	.05				
Fuel K-kill	.0				
Both	.0				
	.05	.05	.05	.05	.05

Table C-2. Results for SC2, 0°, Fully exposed, 2 ft

Threat: SC2
Azimuth: 0 Degrees
Exposure: Fully
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.03				
Reduced Speed, Significant	.01				
Total Immobilization	.09				
	.13	.34	.41	.23	.26
• **Firepower**					
Loss of Main Armament	.10				
Increased Time to Fire	.01				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.11				Operate
	.22	.33	.41	.26	.32
• **Acquisition**					
Reduced Acquisition Capability	.19				
		?	?	?	?
• **Crew**					
Driver	.05				
Commander	.07				
Gunner	.02				
Driver and Commander	.06				
Commander and Gunner	.02				
D, C & G	.00				
	.22	?	?	?	?
• **Communications**					
No External Commo	.03				
No Internal Commo					
No External Commo	.09				
		?	?	?	.23
• **K-Kill**					
Ammo K-kill	.15				
Fuel K-kill	.01				
Both	.00				
	.16	.16	.16	.16	.16

Table C-3. Results for KE1, 1 km, 0°, Fully Exposed, 2 ft

Threat: KE1
Range: 1 km
Azimuth: 0 Degrees
Exposure: Fully
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Reduced Speed Significant	.03				
Total Immobilization	.11				
	.21	.46	.51	.36	.40
• **Firepower**					
Loss of Main Armament	.10				
Increased Time to Fire	.01				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.06				Operate
	.17	.47	.51	.41	.41
• **Acquisition**					
Reduced Acquisition Capability	.11				
		?	?	?	?
• **Crew**					
Driver	.03				
Commander	.04				
Gunner	.04				
Driver and Commander	.18				
Commander and Gunner	.02				
D, C & G	.03				
	.34	?	?	?	?
• **Communications**					
No External Commo	.00				
No Internal Commo					
No External Commo	.05				
		?	?	?	.32
• **K-Kill**					
Ammo K-kill	.22				
Fuel K-kill	.06				
Both	.01				
	.29	.29	.29	.29	.29

Table C-4. Results for KE2, 1 km, 0°, Fully Exposed, 2 ft

Threat: KE2
Range: 1 km
Azimuth: 0 Degrees
Exposure: Fully
Dispersion: 2 Feet

	DS	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.09				
Reduced Speed Significant	.02				
Total Immobilization	.12				
	.23	.51	.61	.43	.47
• **Firepower**					
Loss of Main Armament	.12				
Increased Time to Fire	.01				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.09				Operate
	.22	.56	.61	.49	.48
• **Acquisition**					
Reduced Acquisition Capability	.15				
	.15	?	?	?	?
• **Crew**					
Driver	.03				
Commander	.05				
Gunner	.06				
Driver and Commander	.18				
Commander and Gunner	.05				
D, C & G	.04				
	.41	?	?	?	?
• **Communications**					
No External Commo	.01				
No Internal Commo					
No External Commo	.07				
	.08	?	?	?	.39
• **K-Kill**					
Ammo K-kill	.27				
Fuel K-kill	.07				
Both	.01				
	.35	.35	.35	.35	.35

Table C-5. Results for SC1, 90°, Fully Exposed, 2 ft

Threat: SC1
Azimuth: 90 Degrees
Exposure: Fully
Dispersion: 2Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.03				
Reduced Speed, Significant	.00				
Total Immobilization	.20				
	.23	.59	.65	.50	.51
• **Firepower**					
Loss of Main Armament	.32				
Increased Time to Fire	.03				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.11				Operate
	.46	.57	.60	.54	.58
• **Acquisition**					
Reduced Acquisition Capability	.39				
		?	?	?	?
• **Crew**					
Driver	.02				
Commander	.03				
Gunner	.08				
Driver and Gunner	.02				
Commander and Gunner	.07				
D, C & G	.01				
	.23	?	?	?	?
• **Communications**					
No External Commo	.01				
No Internal Commo					
No External Commo	.31				
	.32	?	?	?	.52
• **K-Kill**					
Ammo K-kill	.39				
Fuel K-kill	.00				
Both	.01				
	.40	.40	.40	.40	.40

Table C-6. Results for SC2, 90°, Fully Exposed 2 ft

Threat: SC2
Azimuth: 90 Degrees
Exposure: Fully
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.04				
Reduced Speed, Significant	.00				
Total Immobilization	.22				
	.26	.65	.72	.54	.57
• **Firepower**					
Loss of Main Armament	.44				
Increased Time to Fire	.03				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.14				Operate
	.61	.70	.74	.65	.71
• **Acquisition**					
Reduced Acquisition Capability	.53				
		?	?	?	?
• **Crew**					
Driver	.02				
Commander	.04				
Gunner	.11				
Driver and Gunner	.02				
Commander and Gunner	.11				
D, C & G	.02				
	.32	?	?	?	?
• **Communications**					
No External Commo	.01				
No Internal Commo					
No External Commo	.41				
	.42	?	?	?	.62
• **K-Kill**					
Ammo K-kill	.47				
Fuel K-kill	.00				
Both	.01				
	.48	.48	.48	.48	.48

Table C-7. Results KE1, 1 km, 90°, Fully Exposed, 2 ft

Threat: KE1, 1 Km.
Azimuth: 90 Degrees
Exposure: Fully
Dispersion: 2 Feet

	DS+	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.02				
Reduced Speed Significant	.01				
Total Immobilization	.19				
	.22	.64	.67	.55	.55
• **Firepower**					
Loss of Main Armament	.23				
Increased Time to Fire	.02				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.15				Operate
	.40	.62	.65	.58	.60
• **Acquisition**					
Reduced Acquisition Capability	.30				
		?	?	?	?
• **Crew**					
Driver	.03				
Commander	.03				
Gunner	.11				
Driver and Commander	.01				
Driver and Gunner	.04				
Commander and Gunner	.13				
D, C & G	.04				
	.39	?	?	?	?
• **Communications**					
No Internal Commo	.01				
No External Commo	.02				
No Internal Commo					
No External Commo	.16				
	.19	?	?	?	.51
• **K-Kill**					
Ammo K-kill	.43				
Fuel K-kill	.01				
Both	.01				
	.45	.45	.45	.45	.45

Table C-8. Results for KE2, 1 km, 90°, Fully Exposed, 2 ft

Threat: KE2
Range: 1 km
Azimuth: 90 Degrees
Exposure: Fully
Dispersion: 2 Feet

	DS	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.02				
Total Immobilization	.19				
	.22	.67	.71	.57	.57
• **Firepower**					
Loss of Main Armament	.07				
Increased Time to Fire	.03				
Unable to Fire on the Move Increased Time to Fire Reduced Delivery Accuracy	.17				Operate
	.46	.65	.69	.62	.65
• **Acquisition**					
Reduced Acquisition Capability	.36				
		?	?	?	?
• **Crew**					
Driver	.03				
Commander	.03				
Gunner	.10				
Driver and Commander	.01				
Driver and Gunner	.04				
Commander and Gunner	.15				
D, C & G	.06				
	.42	?	?	?	?
• **Communications**					
No Internal Commo	.01				
No External Commo	.01				
No Internal Commo No External Commo	.19				
	.21	?	?	?	.54
• **K-Kill**					
Ammo K-kill	.45				
Fuel K-kill	.01				
Both	.01				
	.47	.47	.47	.47	.47

Table C-9. Results for SC1, 0°, Hull Defilade, 2 ft

Threat: SC1
Azimuth: 0 Degrees
Exposure: Defilade
Dispersion: 2Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Reduced Speed, Significant	.00				
Total Immobilization	.00				
	.00	.02	.03	.00	.00
• **Firepower**					
Loss of Main Armament	.01				
Increased Time to Fire	.03				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.04				Operate
	.08	.08	.13	.01	.13
• **Acquisition**					
Reduced Acquisition Capability	.11				
		?	?	?	?
• **Crew**					
Driver	.00				
Commander	.00				
Gunner	.01				
Driver and Commander	.00				
Commander and Gunner	.00				
D, C & G	.00				
	.01	?	?	?	?
• **Communications**					
No External Commo	.01				
No Internal Commo					
No External Commo	.00				
	.01	?	?	?	.02
• **K-Kill**					
Ammo K-kill	.00				
Fuel K-kill	.00				
Both	.00				
	.00	.00	.00	.00	.00

Table C-10. Results for SC2, 0°, Hull Defilade, 2 ft

Threat: SC2
Azimuth: 0 Degrees
Exposure: Defilade
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Total Immobilization	.00				
	.00	.16	.21	.07	.07
• **Firepower**					
Loss of Main Armament	.07				
Increased Time to Fire	.03				
Unable to Fire on the Move Increased Time to Fire Reduced Delivery Accuracy	.18				Operate
	.28	.28	.38	.14	.35
• **Acquisition**					
Reduced Acquisition Capability	.29				
Total Loss of Acquisition	.01				
	.30	?	?	?	?
• **Crew**					
Driver	.00				
Commander	.06				
Gunner	.04				
Driver and Commander	.00				
Commander and Gunner	.02				
D, C & G	.00				
	.01	?	?	?	?
• **Communications**					
No External Commo	.03				
No Internal Commo No External Commo	.06				
	.09	?	?	?	.14
• **K-Kill**					
Ammo K-kill	.07				
Fuel K-kill	.00				
Both	.00				
	.07	.07	.07	.07	.07

Table C-11. Results for KE1, 1 km, 0°, Hull Defilade, 2 ft

Threat: KE1
Range: 1 km
Azimuth: 0 Degrees
Exposure: Defilade
Dispersion: 2 Feet

	DS	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Reduced Speed Significant	.00				
Total Immobilization	.00				
	.00	.07	.09	.05	.05
• **Firepower**					
Loss of Main Armament	.06				
Increased Time to Fire	.02				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.07				Operate
	.15	.18	.24	.10	.23
• **Acquisition**					
Reduced Acquisition Capability	.13				
		?	?	?	?
• **Crew**					
Driver	.00				
Commander	.01				
Gunner	.04				
Commander and Gunner	.01				
	.06	?	?	?	?
• **Communications**					
No External Commo >300 ft	.01				
No External Comm	.01				
No Internal Commo	.01				
No External Commo	.01				
	.03	?	?	?	.06
• **K-Kill**					
Ammo K-kill	.05				
Fuel K-kill	.00				
Both	.00				
	.05	.05	.05	.05	.05

Table C-12. Results for KE2, 1 km, 0°. Hull Defilade, 2 ft

Threat: KE2
Range: 1 km
Azimuth: 0 Degrees
Exposure: Defilade
Dispersion: 2 Feet

	DS	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Reduced Speed Significant	.00				
Total Immobilization	.00				
	.00	.18	.22	.10	.10
• **Firepower**					
Loss of Main Armament	.08				
Increased Time to Fire	.03				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.13				Operate
	.24	.31	.38	.19	.33
• **Acquisition**					
Reduced Acquisition Capability	.20				
		?	?	?	?
• **Crew**					
Driver	.00				
Commander	.02				
Gunner	.10				
Commander and Gunner	.05				
	.17	?	?	?	?
• **Communications**					
No External Commo > 300 ft	.01				
No External Commo	.01				
No Internal Commo					
No External Commo	.03				
	.05	?	?	?	.12
• **K-Kill**					
Ammo K-kill	.10				
Fuel K-kill	.00				
Both	.00				
	.10	.10	.10	.10	.10

Table C-13. Results for SC1, 90°, Hull Defilade, 2 ft

Threat: SC1
Azimuth: 90 Degrees
Exposure: Defilade
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Reduced Speed, Significant	.00				
Total Immobilization	.00				
	.00	.09	.12	.03	.03
• **Firepower**					
Loss of Main Armament	.11				
Increased Time to Fire	.02				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.10				Operate
	.23	.23	.26	.14	.25
• **Acquisition**					
Reduced Acquisition Capability	.21				
		?	?	?	?
• **Crew**					
Driver	.00				
Commander	.02				
Gunner	.02				
Driver and Gunner	.00				
Commander and Gunner	.03				
D, C & G	.00				
	.07	?	?	?	?
• **Communications**					
No External Commo	.01				
No Internal Commo					
No External Commo	.07				
	.08	?	?	?	10
• **K-Kill**					
Ammo K-kill	.03				
Fuel K-kill	.00				
Both	.00				
	.03	.03	.03	.03	.03

Table C-14. Results for SC2, 90°, Hull Defilade, 2 ft

Threat: SC2
Azimuth: 90 Degrees
Exposure: Defilade
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Total Immobilization	.00				
	.00	.14	.18	.05	.05
• **Firepower**					
Loss of Main Armament	.13				
Increased Time to Fire	.02				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.22				Operate
	.37	.33	.41	.18	.39
• **Acquisition**					
Reduced Acquisition Capability	.35				
		?	?	?	?
• **Crew**					
Driver	.00				
Commander	.04				
Gunner	.03				
Driver and Commander	.00				
Commander and Gunner	.06				
D, C & G	.00				
	.13	?	?	?	?
• **Communications**					
No Internal Commo	.01				
No External Commo	.01				
No Internal Commo					
No External Commo	.09				
	.11	?	?	?	.13
• **K-Kill**					
Ammo K-kill	.05				
Both	.00				
	.05	.05	.05	.05	.05

Table C-15. Results for KE1, 1 km, 90°, Hull Defilade, 2 ft

Threat: KE1
Azimuth: 90 Degrees
Exposure: Defilade
Dispersion: 2 Feet

	Degraded States	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Reduced Speed Significant	.00				
Total Immobilization	.00				
	.00	.15	.17	.06	.06
• **Firepower**					
Loss of Main Armament	.18				
Increased Time to Fire	.02				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.07				Operate
	.27	.34	.38	.26	.34
• **Acquisition**					
Reduced Acquisition Capability	.17				
		?	?	?	?
• **Crew**					
Driver	.00				
Commander	.02				
Gunner	.02				
Commander and Gunner	.07				
D, C & G	.00				
	.11	?	?	?	?
• **Communications**					
No Internal Commo	.01				
No External Commo	.00				
No Internal Commo					
No External Commo	.04				
	.05	?	?	?	.11
• **K-Kill**					
Ammo K-kill	.05				
Fuel K-kill	.00				
Both	.00				
	.05	.05	.05	.05	.05

Table C-16. Results for KE2, 1 km, 90°, Hull Defilade, 2 ft

Threat: KE2
Range: 1 km
Azimuth: 90 Degrees
Exposure: Defilade
Dispersion: 2 Feet

	DS	Basic DAL	Aggregated DS		
			'DAL-Like'	Total Kill	Mission Kill
• **Mobility**					
Reduced Speed, Slight	.00				
Reduced Speed Significant	.00				
Total Immobilization	.00				
	.00	.18	.22	.09	.08
• **Firepower**					
Loss of Main Armament	.20				
Increased Time to Fire	.03				
Unable to Fire on the Move					
Increased Time to Fire					
Reduced Delivery Accuracy	.18				
	.41	.31	.38	.30	Operate .44
• **Acquisition**					
Reduced Acquisition Capability	.29				
		?	?	?	?
• **Crew**					
Commander	.01				
Gunner	.03				
Commander and Gunner	.12				
D, C & G	.02				
	.18	?	?	?	?
• **Communications**					
No Internal Commo	.01				
No External Commo	.01				
No Internal Commo					
No External Commo	.05				
	.07	?	?	?	.13
• **K-Kill**					
Ammo K-kill	.08				
Fuel K-kill	.00				
Both	.00				
	..08	.08	.08	.08	.08

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